GEOLOGICAL SURVEY OF OHIO

WILBER STOUT, *State Geologist*

Fourth Series, Bulletin 39

Shales and Surface Clays of Ohio

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COLUMBUS
1938

F. J. HEER PRINTING CO.
COLUMBUS, OHIO
1939

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FOREWORD

This bulletin on the shales and surface clays of Ohio is the result of an investigation conducted jointly by the Geological Survey of Ohio and the Engineering Experiment Station of Ohio State University. The field work for the report was completed during the summer of 1929 when forty-nine samples of shales and surface clays from various parts of the State were collected by R. E. Lamborn of the Survey under the direction of Wilber Stout, State Geologist. The analytical work was performed by Downs Schaaf, chemist for the Survey, who employed the methods of rock analysis adopted by the United States Geological Survey. The work on physical testing was done at the Roseville clay products plant of the Engineering Experiment Station by Chester R. Austin, research engineer of the Station, under the direction of G. A. Bole, research professor.

A preliminary report by Chester R. Austin on the physical tests and properties of the samples was published in January, 1934, as Bulletin No. 81 of the Engineering Experiment Station. A final report, completed so far as resources permit, is here presented, giving a brief account of the general geology of the various deposits, a description of exposures at places of sampling, and the chemical analyses and results of physical tests of the samples. R. E. Lamborn of the Survey has prepared the descriptive material on geology and has compiled the results of testing. In the preparation of the material use has been made of various publications of the Geological Survey of Ohio and unpublished data in the office of the Survey. Other technical publications have also been consulted. References to sources of specific information utilized are given in the text. Chapter IV on testing procedure is repeated as given in Bulletin 81 of the Engineering Experiment Station.

In 1926-1927, twenty-six samples of shales and surface clays from various parts of Ohio were collected by A. E. MacGee of the Columbus Branch of the Bureau of Standards. Chemical analyses of these samples were made by J. F. Klekotka of Washington, D. C. The physical properties in the green and burned states were determined by A. E. MacGee and W. C. O. White of the Columbus Branch of the Bureau. A summary report of the investigation entitled "Properties of Some Ohio Red-Burning Clays," by A. E. MacGee, W. C. O. White, and T. A. Kleinfelter, was published in the Journal of the American Ceramic Society for 1935. The results of an investigation of some of these samples entitled "The Nature of the Glass Phase in Heated Clay Materials," by G. R. Shelton, were also published in the Journal during the same year. The detailed results of the various tests have been compiled by the National Bureau of Standards and with its permission are included in this Bulletin.

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CHAPTER I

GENERAL CHARACTER OF BEDROCK

By Raymond E. Lamborn

The bedrocks exposed at the surface in Ohio are all of sedimentary types, that is, they have been formed from unconsolidated sediments deposited in marine, brackish, or fresh waters. All the common varieties of the sedimentary series are represented, such as limestone, shale, sandstone, and conglomerate, as well as many thin beds of coal, clay, and iron ore. In the western half of the State the bedrock is predominantly limestone and dolomite with minor amounts of calcareous shale. The calcareous shales are most abundant in the southwestern part of the State in Adams, Brown, Clermont, Hamilton, Butler, Warren, Highland, Clinton, Greene, Montgomery, Preble, Miami, and Clark counties. Here thin limestone interstratified with shale is the usual mode of occurrence. In the northwestern corner of the State, including Williams, Fulton, and parts of Lucas, Henry, and Defiance counties, non-calcareous shale is the bedrock lying immediately below the glacial drift.

In contrast to the dominantly calcareous nature of the beds exposed in the western half of Ohio, those in the eastern half are chiefly of the clastic or fragmental varieties. Thick beds of shale, shaly sandstone, and sandstone are the rule although in the Pennsylvanian and Permian systems, which outcrop over an area of about 12,300 square miles in the southeastern portion, thin beds of coal, clay, limestone, iron ore, and conglomerate are present. Lens-like bodies of sandstone are widely distributed but lateral gradation to shale is of common occurrence. Shales of varying character are widely distributed both horizontally and vertically on the outcrop. Measured on the outcrop the total thickness of the sedimentary series in Ohio is in excess of 5,000 feet.

Six of the groups or systems in the historical time classification of rocks are represented in the outcrops of Ohio. The names applied to these groups or systems are world-wide in their application. The chief bases for the subdivision consist of differences in lithologic character of successive beds, evidence of distinct breaks in the succession of deposition of the materials, or evidence of abrupt faunal changes as determined by the study of fossils. The systems of rocks represented in the outcrops in

Ohio are as follows, the oldest appearing at the bottom and the youngest at the top:

Permian
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician

ROCK STRUCTURE

The bedrocks of Ohio are characterized chiefly by their regularity for the strata generally show no marked variation in thickness and the beds usually exhibit little if any departure from a horizontal attitude when observed at a single exposure. If a number of exposures are considered and the beds are correlated or traced from one outcrop to another, the layers are generally found to have an appreciable slope or dip, the amount and direction of which varies with the locality. Faults or distinct breaks displacing the rock strata are generally rare except in a few small areas. The regional slope or dip of the rock series in this State is controlled by the Cincinnati geanticline, a broad structural ridge which forms the western rim of the Appalachian trough. The axis of this structure extends in a general northerly direction from Hamilton and Clermont counties in the southwest towards Toledo on the north. The regional slope or dip of the beds is controlled by this broad structure for the series in northwestern Ohio lie on its western flank and dip in a northwestern direction and the beds of central and eastern Ohio occur on its eastern flank and slope in a southeastern direction.

The most prominent structure in the eastern half of Ohio and secondary only to the Cincinnati anticline in height and extent is the Cambridge arch. This arch is a broad, irregular structure, the axis of which may be represented by a line extending from St. Marys, Pleasant Township, West Virginia, to the northwest in the direction of Cleveland. This structural arch is narrowest and most strongly expressed in Washington, Monroe, and Noble counties, becoming broader and less pronounced to the northwestward. The highest part of this structure is generally near its western edge but the surface of the arch is marked by many structural depressions, noses, and terrace-like features.

From the west edge of the Cambridge arch the beds dip steeply in a westerly direction for a few miles before again rising with the regional slope toward the Cincinnati arch. A structural trough is thus formed which parallels the Cambridge arch and lies a few miles to the west of it. As the axis of this trough can be roughly represented by a line extending from Lorain, Lorain County, through Millersburg, and Coshocton, to the

Ohio River near Parkersburg, West Virginia, it can be appropriately called the Parkersburg-Lorain syncline. This syncline is best developed in the Marietta region where the bottom is four or five miles in width and nearly flat in an east and west direction and where the structure rises 300 feet or more to the edge of the Cambridge arch to the eastward. The trough becomes narrower and shallower to the northwest of Marietta in the east-central part of the State, and in Lorain County in the northern part it is poorly defined.

The crest of the Cincinnati geanticline is broad and flat in southwestern Ohio, where a branch structure extends to the northwest in Indiana in the direction of Chicago.[1] Over many of the counties in the southwest corner of the State the structure of the surface rock is flat or gently undulating in an east-west direction across the crest of this arch. The axis of the arch as shown on the top of the Trenton limestone is well defined north of Greene County where it plunges in a direction about N. 16° E. The arch dies out in southwestern Ontario. The dip of the beds in a northerly direction along the axis of the fold from northwestern Clark County to southern Hancock County is about 5.6 feet per mile as measured on the base of the Brassfield limestone ("Packer shell" of the driller). The symmetry of the northern end of the geanticline in Ohio is broken by the presence of a fault or steep monocline having a direction N. 10° W. This break is known to extend from northern Lucas County to central Hancock County. The rocks west of this break as measured on the top of the Trenton limestone are known to be displaced downward from 100 to 200 feet.

From the crest of the Cincinnati geanticline the rocks in the northwest corner of the State dip steeply into the Michigan Basin in a direction a little west of north. East of the axis of the fold the regional slope is essentially east in west-central Ohio. As computed from well records, the dip of the Brassfield limestone from the axis near Findlay, Hancock County, east to New London, Huron County, is about 27.8 feet per mile. From northwestern Clark County to Columbus, Franklin County, the fall, measured on the same limestone, is about 17.3 feet per mile. In the eastern half of Ohio and particularly in the coal-bearing series, the dip of the beds has been accurately figured from surface exposures. It is found that the southern component of the dip is much greater than the eastern component in northeastern Ohio but that the eastern component of the dip increases progressively southwest along the belt of outcrops and that in southern Ohio the eastern component is much the greater. Thus in Columbiana County the fall is 3.8 feet per mile to the east and 10.7 feet per mile to the south.[2] In Muskingum County the general slope to the east is 24 feet per mile and to the south 9½ feet per mile, giving a maxi-

[1] Carman J. E., and Stout, Wilber, Problems of Petroleum Geology, American Association of Petroleum Geologists, 1934, pp. 521-529.
[2] Geol. Survey Ohio, 4th Ser., Bull. 28, p. 50, 1924.

mum dip of 24.7 feet per mile in a direction S. 66°-37′ E.[1] In Vinton County the inclination to the east is 28 feet per mile and the inclination to the south is 12 feet per mile, giving a maximum fall of about 33 feet per mile in a direction S. 66°-48′ E.[2]

The regularity of dip on the eastern flank of the Cincinnati geanticline from its axis to the trough of the Parkersburg-Lorain syncline is broken by the presence of many structural noses. These noses have a general northwest-southeast axial trend and vary in general from two to twenty miles in length. Structural noses of this type undoubtedly occur high on the flank near the axis and may account in part for some accumulation of oil and gas in the Trenton field. They are best known, however, through east-central Ohio from western Holmes County to southern Lawrence County. Structural noses are numerous in a belt extending from southern Lawrence County to southern Hocking County where they have an axial trend around 35° to 40° W. of N. They are likewise known in eastern Meigs County, eastern Athens County, north-central Morgan County, and in Muskingum County, but their axial trend is not so uniform in direction.

Along the axis of the Parkersburg-Lorain syncline the rock strata pitch 16 feet per mile in a direction S. 13.75° E. from Millersburg to the Muskingum River in Washington County. The structure rises abruptly from the bottom of this trough to form a structural crest at the western edge of the Cambridge arch. In Jackson Township, Noble County, the structural rise is 220 feet in 3.5 miles in a direction N. 66.5° E. Through Brookfield and Buffalo townships, Noble County, the ascent is 320 feet in 8.8 miles in a direction N. 50° E. The maximum rise at Millersburg, Holmes County, where the trough is narrow and constricted, is 160 feet in 4 miles in a direction N. 67.5° E. From the high crest at the western edge of the Cambridge arch, the beds fall irregularly to the southeast across the broad sloping top of the structure until the eastern edge is reached, where the regional dip to the southeast is increased. The upper surface of the arch is marked by many structural depressions and noses. The noses are most numerous in Washington, Monroe, and Noble counties where in general their axial trend parallels the trend of the arch. It is thus apparent that much of Ohio, although marked by many structural irregularities, lies on the western side of a large structural trough whose western rim is the Cincinnati axis.

OUTCROP RELATIONS OF BEDS AND THEIR ORIGIN

During the geologic past, represented by the rock outcrops in Ohio, the land surface has undergone many changes of level with respect to the sea. At times when the land surface stood above sea level it was being eroded and was yielding sediments to the submerged areas surrounding it.

[1] Geol. Survey Ohio, 4th Ser., Bull. 21, pp. 31–33, 1918.
[2] Geol. Survey Ohio, 4th Ser., Bull. 31, pp. 10–11, 1927.

At other times the surface seemed to slowly sink, permitting the ocean to gradually encroach upon its borders forming embayments or shallow inland seas in which sediments were deposited. The sediments forming the Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian rock systems were laid down during periods of partial or complete submergence. The various rock systems are in general separated by wide-spread unconformities or irregular erosion surfaces representing in general periods of land emergence.

In addition to the slow periodic movement of the land mass, differential movements within the land mass also took place. In early geologic times a deep trough began to develop in the region of the Appalachian Mountains and its development continued by differential sinking through many succeeding periods. The first stage in the formation of the western rim of this trough apparently began at the end of the Ordovician period with differential uplift in the region of the Cincinnati axis. With the beginning of the periods of deposition, land submergence began along the axis of this trough. With the progress of the periods there was in general a tendency for the inland seas to spread westward, encroaching upon the Cincinnati arch, and in the case of the Silurian and Devonian in Ohio, entirely submerging it before the end of the periods. Into the seas thus formed great quantities of clastic sediments were deposited, coming chiefly from the highland masses existing at various times on the eastern, northeastern, northern, and southeastern borders. Clastic sediments were deposited in greatest thickness adjacent to the greatest highlands or in the region of the axis of the trough, leading to thick deposits of sedimentary rock. In the shallow seas relatively far from land, shelled forms of marine life flourished and relatively thin deposits of limestone and dolomite were formed.

The rock outcrops of the Silurian system and of the Lower and Middle Devonian systems in Ohio are composed chiefly of limetsones and dolomites with minor amounts of soft calcareous shales. These deposits were formed in shallow seas relatively free from land-derived sediments. With the formation of the Upper Devonian and Mississippian deposits in Ohio the zones of sedimentation had shifted as the deposits are in large part of the clastic or land-derived type. The thickening of the beds to the eastward in Ohio toward the axis of the trough can be illustrated by the Ohio shale: In eastern Franklin County the thickness is approximately 650 feet while in eastern Monroe County the thickness of the same series approaches 4,000 feet. The Big Lime series, including the Middle and Upper Silurian and Lower and Middle Devonian limestones and dolomites, likewise thicken under cover to the northeast in Ohio. During the Pennsylvanian period the areas of deposition stood near sea level, permitting the existence of broad marshes or shallow seas in which alternately sediments were being deposited and plant life flourished. Fresh or brackish water conditions prevailed during the deposition of the upper half of the Pennsylvanian system in Ohio and continued throughout the Permian. The region of the Cincinnati axis in Ohio was probably above sea level during the Pennsylvanian and Permian periods.

At the end of Permian time much of the continent was elevated and crustal deformation took place in the region of the trough, marking the first stage in the formation of the Appalachian Mountains.

On the new land surface which was thus forming the various agents of weathering and erosion began their gradational work. Streams were formed on the surface which by deepening, lengthening, and broadening their channels, and by the development of innumerable tributaries, tended to dissect the surface and to produce erosional surfaces at lower levels. Later periods of uplift occurred which rejuvenated the streams, causing them to degrade their valleys to lower levels. Remnants of no less than three old erosion surfaces remain today, the highest occurring at an altitude of 1,200 feet or more in eastern Ohio.

The region of the Cincinnati axis in Ohio was probably a land mass during the deposition of the Pennsylvanian and Permian beds to the eastward and was probably undergoing erosional degradation long before the close of Permian time. During the long period of time that has elapsed, the younger beds have been removed from the region of the axis where the Ordovician and Silurian rocks are now exposed at the surface. In going eastward from the axis, younger beds appear successively at the surface until southeastern Ohio is reached where the uppermost rocks are of Permian age. Thus with the elevation of the land and with the erosion which has followed, a gradational surface has been produced which bevels the formations. The rock systems outcrop as more or less parallel bands of varying width extending in a general northeast-southwest direction. The distribution of the various groups or systems in Ohio is shown on the accompanying map.

GENERAL CHARACTER OF SHALE

Salient features of the character, mode of formation, composition, and classification of shales are described briefly in the following paragraphs.

Shale is a variety of sedimentary rock which has resulted from the consolidation of more or less thinly laminated or bedded silts and clays. Typical shales possess fissility or the property of splitting with comparative ease along the planes of lamination or bedding. In general, shale is less weather resistant than most other varieties of sedimentary rocks. It is generally softer than slate with which some shales are often confused, but unlike slate it soon crumbles on exposure to the elements of weathering. Hand specimens of typical shale are distinguished from sandstones and conglomerates by the smaller grain size and by the fissility; from coal measure clay and mudstone by its fissility; and from limestone and dolomite by its fissility and low carbonate content.

The composition of shales is variable as they are assemblages of many mineral substances of different chemical composition. The chief mineral constituents found in shale are hydrated aluminum silicates of varying composition, quartz, rutile, apatite, calcite, dolomite, and iron oxides. Organic material is generally present in small amounts. The hydrated silicates and quartz make up a large part of the average shale and in themselves produce a rock which is white, green, or greenish gray in color. Iron compounds and organic material on the other hand usually occur in relatively small amounts, but they are strong coloring pigments. Dark bluish gray, dark brown, and black colors are usually found when finely divided organic material is present in the shale. Where iron oxide occurs in the absence of much organic matter the shale may be either buff, yellowish brown, brown, or red in color, depending upon the quantity of oxide present, its degree of hydration, or its evenness of distribution in the rock. Green or greenish gray colors are characteristic of unweathered shale rich in either iron carbonates or chloritic material and poor in organic matter.

In their field relationships shale beds a few feet to hundreds of feet in thickness occur associated with sandstone, limestone, coal, and claystone, into which they may grade both laterally and vertically by changes in composition, structure, and texture. As quartz increases in percentage and size of grain the material passes by gradation to shaly sandstone and finally sandstone; with an increase in the percentage of calcium carbonate the gradations are to limestone; as carbonaceous material becomes greater in amount, the transition is to bone coal and coal; and as the fissility or shaly structure disappears, siltstone is produced.

Shales showing a great range in chemical composition and physical properties are widely distributed on the outcrop and they show no relation to present geographic boundaries. In all cases the dominant chemical character of the shale has been determined by the composition and condition of deposition of the silt or clay from which it was derived, modified to some slight degree perhaps by the action of weathering agents on the present outcrop.

THE FORMATION OF SHALE

Shale is of sedimentary origin, that is, the material has been derived from pre-existing forms of rock through the operation of sedimentary processes. The pre-existing type of rock may have been shale or, to trace the origin back to its ultimate source, igneous rock, which is the parent of all rock forms and which in turn has been formed by the consolidation of material from a magmatic or fluid state. The processes involved in the formation of shale include: (1) Weathering or the breaking up of rock material under the influence of the weather; (2) transportation and deposition of the products of rock weathering; (3) subsequent consolidation of rock debris.

Weathering

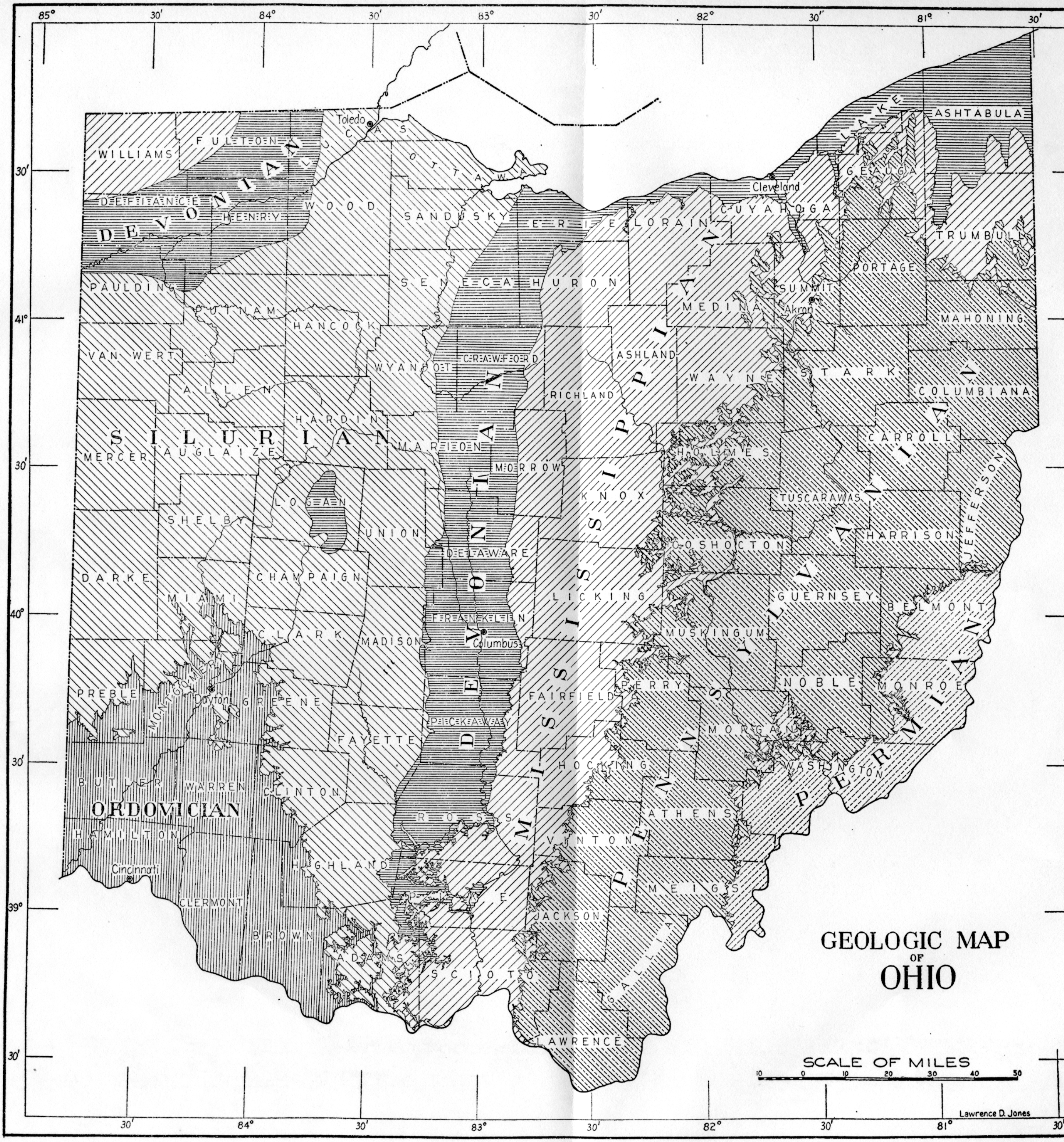
By processes which are in part mechanical and in part chemical in nature, rock which is exposed to the agents of the weather may be disrupted mechanically and so changed in chemical composition that it bears little resemblance to the original rock. These changes are the result of weathering. The rate of weathering depends on the physical and chemical constitution of the rock, its condition of exposure, and the nature of the weather. In general weathering is most intensive at the surface and diminishes rapidly with depth.

Mechanical weathering or *disintegration* is rock disruption which does not involve a change in chemical composition. Such changes are brought about chiefly through expansion and contraction of exposed rock with daily temperature changes. The freezing and thawing of pure water with daily temperature change, the impact of wind and rain on rock surfaces, the wedge work of roots in cracks and crevices, and the action of gravity in causing landslides are also important agents in the general work of disintegration.

Chemical weathering or *decomposition* involves the chemical union of carbon dioxide and oxygen of the air in the presence of water and the union of water itself with various constituents in the rock to produce new chemical compounds. Such chemical changes tend to produce compounds of greater chemical stability under weathering conditions. Changes of this type are most important in the weathering of crystalline igneous and metamorphic rocks in which the mineral constituents were formed under conditions of high pressure and high temperatures. They are also apparent in the weathering of sedimentary rocks. Solution is an important agent in the removal of the soluble products formed through decomposition.

Disintegration and chemical decomposition have both played a part in the production of the raw materials from which shales are formed. In the weathering of a rock surface the change generally apparent at first consists in a disintegration or mechanical disruption of the rock material. As disruption proceeds the surface exposed to the weather becomes greater and chemical decomposition tends to increase. The rate of chemical change is promoted by warm temperatures and an abundance of atmospheric moisture.

The crystalline igneous rocks are generally made up in large part of silicates with minor amounts of oxides, sulphides, chromates, fluorides, etc. Although occurring in widely varying proportions, a few groups of


GEOLOGIC MAP OF OHIO
SCALE OF MILES
10 0 10 20 30 40 50
Lawrence D. Jones
DEVONIAN
SILURIAN
ORDOVICIAN
MISSISSIPPIAN
PENNSYLVANIAN
PERMIAN
Toledo
Cleveland
Akron
Columbus
Dayton
Cincinnati
WILLIAMS
FULTON
LUCAS
OTTAWA
DEFIANCE
HENRY
WOOD
SANDUSKY
ERIE
LORAIN
CUYAHOGA
LAKE
GEAUGA
ASHTABULA
TRUMBULL
PORTAGE
SUMMIT
MEDINA
PAULDING
PUTNAM
HANCOCK
SENECA
HURON
MAHONING
VAN WERT
ALLEN
WYANDOT
CRAWFORD
ASHLAND
WAYNE
STARK
COLUMBIANA
RICHLAND
HARDIN
MARION
MORROW
HOLMES
CARROLL
MERCER
AUGLAIZE
LOGAN
UNION
KNOX
TUSCARAWAS
JEFFERSON
SHELBY
DELAWARE
COSHOCTON
HARRISON
DARKE
MIAMI
CHAMPAIGN
LICKING
GUERNSEY
BELMONT
CLARK
MADISON
FRANKLIN
MUSKINGUM
PREBLE
MONTGOMERY
GREENE
FAIRFIELD
PERRY
NOBLE
MONROE
FAYETTE
PICKAWAY
MORGAN
WASHINGTON
BUTLER
WARREN
CLINTON
HOCKING
ATHENS
HAMILTON
ROSS
VINTON
HIGHLAND
MEIGS
CLERMONT
JACKSON
BROWN
ADAMS
SCIOTO
GALLIA
LAWRENCE
85°
84°
83°
82°
81°
41°
40°
39°
30'

minerals make up a large percentage of the average igneous rock. The proportions as given by Clarke are as follows:[1]

Average Mineral Composition of Igneous Rocks

	Per Cent
Feldspars (aluminum silicates of K. Na. Ca. Ba.)	59.5
Hornblende and pyroxene (chiefly metasilicates of Ca. Mg. Mn. Na. Fe. and Al.)	16.8
Quartz SiO_2	12.0
Biotite (aluminum orthosilicates of K. Mg. and Fe.)	3.8
Titanium minerals (oxides and calcium aluminum silicates)	1.5
Apatite (calcium phosphate)	.6
All others	5.8

In the decomposition of igneous rocks meteoric waters and carbon dioxide and oxygen are the important agents. Meteoric waters carrying carbon dioxide in solution wet the rock surface and penetrate the pores and fissures for many feet below the surface. Practically all minerals, certainly all the important ones, are attacked by such waters. Of those silicates occurring in largest proportions in igneous rocks, the hornblendes and pyroxenes are attacked most readily, the feldspars next in order, followed by the micas. Pyrite is decomposed and quartz is dissolved slightly. Apatite and other accessory minerals are affected to a slight extent.[2]

The first steps in the decomposition of the natural silicates under ordinary weathering conditions are solution and hydrolysis. As indicated by Messrs. Rogers in 1848,[3] and substantiated by many experiments since that time,[4] the silicate minerals are generally soluble in carbonated water and many are slightly soluble in pure water, the solutions in both cases giving alkaline reactions. Such silicate minerals as hornblende, pyroxene, feldspars, and micas are for the most part salts of the bases sodium, potassium, calcium, magnesium, and ferrous iron combined with the comparatively weak silicic or alumino-silicic acid. Solutions of such salts in water tend to hydrolyze, producing silicic or alumino-silicic acid and hydroxides of the bases. When carbon dioxide is present in solution the hydroxides are converted into carbonates. As it is a recognized fact from observation that the complex silicates tend to break down in the zone of weathering with the separation of silica, it must be assumed that the silicic and alumino-silicic acids formed by hydrolysis are unstable and that they tend to break down into more stable compounds with the liberation of silica.

The changes are illustrated by the following reactions which show the decomposition of orthoclase feldspar under ordinary conditions of weathering.[5]

[1] Clarke, F. W., U. S. Geol. Survey, Bull. 770, p. 423, 1924.
[2] Idem., p. 484.
[3] Rogers, W. B., and Rogers, R. E., Am. Jour. Sci., 2nd Ser., Vol. 5, pp. 401-405, 1848.
[4] Cameron, F. K., and Bell, J. M., U. S. Dept. Agr., Bur. Soils, Bull. 30.
[5] Idem.

$$KAlSi_3O_8 + H_2O = KOH - HAlSi_3O_8 \text{ (hydrolysis)}$$
$$2K(OH) + H_2O + CO_2 = K_2CO_3 + 2H_2O \text{ (carbonation)}$$
$$HAlSi_3O_8 = HAlSiO_4 + 2SiO_2 \text{ (desilication)}$$
$$2HAlSiO_4 + H_2O = H_4Al_2Si_2O_9$$

Combining the above reactions we have:

$$2KAlSi_3O_8 + H_2O + CO_2 = K_2CO_3 + 4SiO_2 + H_4Al_2Si_2O_9$$

The products of decomposition in this example are potassium carbonate (K_2CO_3), Silica (SiO_2), and the hydrated aluminum silicate, kaolin, ($H_4Al_2Si_2O_9$). Where one or more of the bases, calcium, sodium, manganese, or ferrous iron occur in the complex silicates, such as plagioclase feldspars, hornblende, the pyroxenes, and biotite mica, they are converted to carbonates under ordinary conditions of weathering. Magnesium, however, is not fully liberated as a carbonate but tends to form with the silicic or alumino-silicic acids the insoluble magnesium silicate talc, or the magnesium aluminum silicate chlorite. Quartz is not greatly affected by ordinary conditions of weathering although a small part may be lost in solution. Apatite is readily decomposed by carbonated waters yielding lime and phosphoric acid.[1]

In addition to those minerals considered, many others including oxides and silicates are present in small quantities in igneous rock. One of the most important accessory minerals is the iron sulphide, pyrite, as it yields sulphuric acid and iron oxide on weathering. The alteration may be expressed by the following reactions.[2]

$$FeS_2 + 3O_2 = FeSO_4 + SO_2$$
$$2SO_2 + O_2 + 2H_2O = 2H_2SO_4$$
$$4FeSO_4 + 10H_2O + O_2 = 4Fe(OH)_3 + 4H_2SO_4$$
$$4Fe(OH)_3 = 2Fe_2O_3.3H_2O + 3H_2O$$

Combining the above as one reaction we have:

$$4FeS_2 + 11H_2O + 15O_2 = 2Fe_2O_3.3H_2O + 8H_2SO_4$$

The products of complete oxidation by weathering are the hydrated iron oxide limonite and sulphuric acid. The sulphuric acid in solution in ground waters intensifies the weathering process.

The products of decomposition of minerals in igneous rocks under ordinary conditions are of two types: The first type consists chiefly of carbonates of the bases potassium, sodium, calcium, magnesium, iron, and manganese, all of which are relatively soluble in ground waters containing an excess of carbon dioxide and are subject to removal in solution. The second class consists for the most part of the insoluble hydrated silicates of the kaolin group, the serpentine-talc group, the chlorite group, the zeolite group, and the epidote group; the insoluble oxides of iron, titanium, and silicon; and fragments of unaltered rock. The insoluble products of

[1] Clarke, F. W., U. S. Geol. Survey, Bull. 770, p. 358, 1924.
[2] Buck, S. P., and Downs, R., The Oxidation of Pyritic Sulphur in Coal Mines, Am. Inst. Min. Met. Eng., Tech. Pub. 769.

weathering with or without fragments of unaltered rock are the raw materials for the production of the clastic sediments, from which in part shale is formed. The transportation, deposition, and consolidation of the material are necessary to complete the process of formation of shale.

The physical character of the materials formed by weathering is variable, depending on the nature of the weathering process, the mineral composition of the rock, and the length of time involved. Boulders, cobbles, and sands predominate in residual surface mantles where disintegration is the chief mode of weathering, where the bedrock is not susceptible to rapid chemical alteration, or where the time interval is short. Under conditions of climate and bedrock favoring extensive decomposition and with the volume expansion and destruction of rock structures resulting from such alteration, the weathered mantles produced consist for the most part of unaltered rock fragments embedded in a matrix of silts and clays. The segregation of materials of similar texture or size occurs during the process of transportation and deposition. As the finer-grained products of weathering are removed by the transporting agents and as the blanketing effect produced by the products of rock decomposition is reduced, the rate of weathering tends to increase.

Transportation of Rock Waste

As soon as the bedrock has been disrupted by the physical forces of weathering or has been changed in composition through chemical action, the material is in a state to be transported. In arid regions where little vegetation is present the wind picks up the fine particles and transports them long distances in suspension as evidenced by the sand and dust storms of the Sahara and the Great American deserts. In humid regions, wind action is less effective but other agents such as the action of frost and running water are of more importance. The expansion and contraction caused by the alternate freezing and thawing of soil materials saturated with water cause a slow creep down hill in the direction of slope. The action of gravity also causes landslides. In humid regions the most important agent of transportation is the water which drains from the land surface. The source of such water is rainfall. During periods of rainfall some of the water passes off immediately into the creeks and streams, but large quantities are absorbed by the porous mantle of rock waste at the surface, later to supply the needs of vegetation, to be directly evaporated from the soil, to supply water wells, or to issue at the surface as springs.

The immediate run-off is a most effective agent in the transportation of rock waste. The silts, sands, and clays which have been produced by mechanical and chemical processes of weathering are carried along in suspension in the waters while the larger fragments are rolled or shoved along the stream bottom by the force of the current. The quantity of material which can be carried in this way is enormous. An increase of eight times the volume of a stream doubles its velocity and this doubling of the velocity increases the transporting power sixty-four times. Thus the transporting ability of streams at flood stage can be appreciated.

The soluble substances produced by weathering go into solution in surface waters which either pass into the immediate run-off or are carried downward into pores, cracks, and crevices as ground waters.

Deposition of Rock Waste

The deposition of materials carried in suspension in water is brought about by a check in velocity of water. When streams are heavily loaded with materials in suspension, that is, when the waters are carrying about all the material that they are capable of holding, any slight check in the velocity of movement causes deposition. A decrease in water velocity takes place along river courses where there is a sudden change in the direction of the current, a decrease in the gradient or slope of the bed, where the waters become shallower and the frictional resistance to water movement becomes greater, or where the volume of the water decreases as by evaporation. Deposits formed by a check in water velocity are found along all river valleys. Deposits in the channel often take the form of sand bars which may ultimately form islands. Valley bottoms are often deeply covered with alluvial materials consisting of pure sands and silts laid down during periods of high water when the valley bottom is flooded.

Although a portion of a river's burden of rock waste may find a temporary resting place along the stream's course, it is ultimately carried to the sea. Here the suspended material is deposited as the velocity of the water is checked while the material in solution is added to the salts dissolved in the sea water. The deposited material may build up deltas along protected shores, but a large part is distributed laterally by wave and current action, to form submarine platforms bordering the continental masses. In the distribution process the coarse materials tend to be deposited near the shore where the water is shallow and the wave and current action is strong. The finer materials, such as the silts and clays which remain in suspension for a longer period of time, are carried farther from shore and deposited in deeper waters where agitation by wave and current action is less vigorous. Beyond the zone of silts and muds, shell-bearing forms of marine life flourish if the conditions of food supply, depth of water, temperature, light, etc., are favorable. The shell material from such organic life, when consolidated, forms limestone. Between the zones of deposition of sands and silts on the one hand or of muds and shell deposits on the other there are zones of intermingled sands and silts or of intermingled muds and calcium carbonate deposits. Expressed in other words, beds of sand near shore become finer grained outward and pass without a clear line of separation into the silts; likewise there is a lateral gradation between the muds and the calcium carbonate deposits, with a decrease in the silty materials, away from the shore line.

During the process of deposition there is a tendency for the zones of deposition to shift, being relatively near shore during periods of quiet and relatively far from shore during periods of storm. Vertical variations in the texture of materials within the silt zone are therefore produced. On consolidation planes of relative weakness develop in the finer-grained materials, producing the characteristic shaly structure.

Consolidation of Sediments

As the sediments increase in thickness by deposition there is a tendency toward consolidation. The coarsely grained deposits, such as sands and gravels, are consolidated chiefly by cementation. The water saturating these sediments and carrying calcium carbonate, iron carbonate, or silica in solution may deposit these materials as films around the grains. The intergrowth of these films at points of contact binds the material together. Further deposition of material from solution may take place, partly or completely filling the voids. In the consolidation of the more soluble materials, such as calcium carbonate deposits, partial recrystallization plays an important part.

In the consolidation of muds and silts to form shale, weight pressure is important. The mud and silt particles are smaller in size than sand and they tend to pack closer together leaving smaller voids. They are, therefore, less permeable to circulating waters. While cementation is not entirely wanting, especially in the sandy varieties, and crystallization of the soluble materials may take place to some extent, the chief process in the consolidation to shale is a compacting or welding of the material as a result of weight pressure. Colloidal clay material may aid as a binder in this process. The density is increased and much of the mechanically inclosed water is eliminated during the process of consolidation.

Shale From Sedimentary Rocks

Sedimentary rocks are broken up by weathering and the materials are transported, re-deposited, and again consolidated. The forms so derived may not necessarily vary greatly in composition from the original. The common varieties of sedimentary rock, with the exception of limestone and dolomite, are composed in large part of the insoluble residues resulting from the weathering process. The erosion of such rocks, therefore, is chiefly a mechanical process of disruption and redistribution of materials in which gravels form conglomerates, sands form sandstones, and silts form a later generation of shale deposits.

CHEMICAL COMPOSITION OF SHALE

As one would expect from its mode of origin, the relative proportions of the mineral constituents composing shale vary within wide limits. At the present stage little definite information is available on the quantitative mineralogical composition. Variations, however, are reflected in the chemical composition. Analyses of shales of various types are given below.

Analyses of Shales

	1	2	3	4	5	6
SiO_2	58.38	75.24	57.20	60.65	25.05	59.95
Al_2O_3	15.47	10.96	13.06	11.62	8.28	17.99
Fe_2O_3	4.03	4.01	14.08	.36	.27	4.62
FeO	2.46	....	1.36	....	2.41	2.61
MgO	2.45	.61	1.62	1.90	2.61	1.49
CaO	3.12	.40	.65	1.44	27.87	.75
Na_2O	1.31	.51	.35	.60	....	.28
K_2O	3.25	2.63	2.60	3.10	....	2.75
H_2O-	5.02	.62	1.96	1.19	1.44	1.30
H_2O+		....	5.45	3.77	2.86	5.49
TiO_2	.65	.90	1.20	.62	....	1.07
CO_2	2.64	....	.25	1.65	24.20	.89
P_2O_5	.17	.15	.15	.18	.08	.17
SO_3	.65	....	....	.07	....	....
C	.81	....	.18	9.20	....	.51
MnO	trace	trace	.04	.04	4.11	.06
S	....	....	.04	....	....	.14
FeS_2	....	....	....	3.20	....	....

1. Average or composite analysis of 78 shales.
   (U. S. Geol. Survey, Bull. 770, p. 631, 1924.)
2. Pottsville shale, near Wadsworth, Medina County, Ohio.
   Analysis by U. S. Bureau of Mines.
3. Bedford shale, near Cleveland, Cuyahoga County, Ohio.
   Downs Schaaf, analyst.
4. Ohio shale near Zanesfield, Logan County, Ohio.
   Samples by Wilber Stout and Walter Stout. Downs Schaaf, analyst.
5. Cretaceous shale, Mamet Diable, California.
   W. H. Melville, analyst (U. S. Geol. Survey, Bull. 770, p. 552, 1924.)
6. Average of 35 analyses of shales utilized in the ceramic industry.
   Analyses by Downs Schaaf.

CLASSIFICATION OF SHALE

Variations in the physical properties of shale are due in large part to variations in the mineral constituents and to conditions of formation. In a field classification of shales a number of different kinds are recognized.

Clay Shale

The distinguishing characteristic of clay shale is the smooth greasy sensation which it gives to the touch. Shales of this type have a relatively high percentage of very fine-grained materials and a relatively low percentage of coarse silts. Colloidal clay material is expected in relatively large amounts. In some clay shales lamination is well developed with the laminae paper-like in thickness but in other shales of the class this structural feature is imperfectly developed. The color may vary greatly but gray, greenish gray, buff, or red are most common. Clay shales do not resist weathering well as they crumble quickly to a soft sticky mass. The silica content is generally below the average and the alumina content above the average for the shales as a group.

Sandy or Arenaceous Shale

As distinguished from clay shale, the sandy or arenaceous shale is characterized by the presence of sands and coarse silts in noticeable amounts. The sands and coarse silts may be fragments of quartz or other unaltered or slowly decomposable minerals. Where quartz grains occur in large amounts the rock is considered to be a siliceous shale. The zone of deposition is in general intermediate between the clay shale on the one hand and the fine-grained sandstones on the other. Lamination is present but not so perfectly developed nor in general are the laminae as thin as they are in the clay shale. Sandy or arenaceous shale is generally more weather resistant than clay shale. The colors are variable but light shades such as gray, buff, or yellowish brown usually predominate.

Calcareous Shale

Calcareous shale contains a relatively high percentage of calcium carbonate. The calcium carbonate occurs in a finely divided state disseminated throughout the rock mass, as small nodular concretionary-like masses embedded in the shale or as shell remains of former aquatic life. The calcium carbonate may have been introduced as calcareous silt but the action of bacteria and algae in precipitating calcium carbonate from solution and the loss of carbon dioxide from solution by other organic means or by physical means undoubtedly have played a part. As the percentage of calcium carbonate increases, the calcareous shale passes by gradation to limestone. Calcareous shale may be sandy or arenaceous, ferruginous, or carbonaceous. Calcium carbonate gives a gray color to shale. Where iron compounds or carbonaceous materials are present in large amounts, the color may be red, buff, yellowish brown, bluish gray, or black.

Ferruginous Shale

Iron is present in practically all shales in chemical combination with other elements. The red, reddish brown, and yellowish brown colors of unweathered shale are due to the presence of iron compounds. Unweathered shale of marine origin, rich in iron compounds and poor in organic material, is prevailingly gray, greenish gray, or bluish gray in color. On weathering red, buff, yellowish brown, and brown shades are produced by the oxidation and hydration of the iron compounds. If much carbonaceous material is present in the shale the ferruginous character of the beds is not so apparent until the organic material has been removed in large part from the surface layers by weathering. In general, a shale is said to be ferruginous when the iron-bearing minerals are conspicuous in the unweathered rock or when marked red, brown, or yellowish brown colors are produced on weathering. A high iron content is accompanied by an appreciable increase in specific gravity.

The chief mineral compounds of iron in shale are hematite (Fe_2O_3), limonite ($2Fe_2O_3\ 3H_2O$), siderite ($FeCO_3$), pyrite and marcasite (FeS_2), and iron-bearing silicates of varying composition of both primary and secondary origin. In the decomposition of the iron-bearing silicates in igneous rocks ferrous iron is liberated as a carbonate which goes into solution readily in ground waters containing an excess of carbon dioxide. When air has free access the ferrous carbonate is decomposed and an insoluble oxide is formed. In regions subject to seasonal or cyclical aridity the insoluble oxides generally result from weathering and the sediments are highly colored, pink, red, and reddish brown.

In the zones of sedimentation, oxidizing or reducing conditions may exist, depending on the balance between available oxygen and decaying organic matter. Red and brown silts bearing insoluble oxides of iron tend to produce red and brown shales. Decaying organic material buried in the silts tends to reduce the ferric oxides with a consequent change in color of the sediments. To assure complete reduction of the oxides of iron, sufficient organic material must be present to maintain reducing conditions at varying rates of sedimentation. The red shales of the Bedford formation and the red and variegated shales of certain horizons in the Conemaugh series and in the Permian system represent periods when reducing conditions were not maintained. Ferrous carbonate transported with muds and silts from humid regions is generally deposited in large part as ferrous carbonate. The prevailing colors of shale formed from such sediments are white, gray, light green, bluish gray, and black.

The ferrous sulphide pyrite (marcasite), which is readily recognized by its brass or greenish brass metallic appearance, is found in nearly all shales but is especially common in the carbonaceous varieties. It is most conspicuous in shales as nodular concretionary forms of varying shape and size but it likewise occurs as small grains scattered through the rock.

Much of the pyrite in shale has been formed during the consolidation of the material. The soluble ferrous carbonate and ferrous sulphate mingle freely with sediments, where in the presence of bacteria associated in the decomposition of organic material the ferrous solutions are decomposed and a hydrated ferrous sulphide is precipitated. By a loss of water and the addition of sulphur from muds the ferrous sulphide is gradually changed to pyrite during the consolidation of the material.[1] On complete weathering pyrite alters to the hydrated iron oxide limonite and sulphuric acid.

The iron-bearing silicates in shale include fragments of unaltered minerals derived from pre-existing rocks and secondary silicates, of which glauconite is perhaps the most widely distributed. Glauconite is a hydrated potassium iron-bearing silicate in which potassium may be partly replaced by other bases and ferric iron may be partly replaced by aluminum. It is believed to have been formed by the interaction of decaying organic material on hydrated aluminum silicates in the presence of sea water. Glauconite usually occurs as minute greenish-colored grains. It is never an abundant mineral in shale although it is expected in small quantities in the calcareous varieties.

Carbonaceous Shale

Shale is said to be carbonaceous when the content of organic material is great enough to give a dark brown or black color to the unweathered rock. In addition to the content of organic material, shale may also be ferruginous, calcareous, and arenaceous in character. As the percentage of carbonaceous material increases the shale passes by gradation to bone shale. Pyrite is especially abundant in carbonaceous shale, occurring usually as disseminated grains and in nodular concretionary form. Where fossils are present they are usually pyritized. Lamination is generally well developed and the rock usually splits with comparative ease into thin slab-like pieces.

The mixtures of silt, clay, and organic matter from which carbonaceous shales have been formed by consolidation accumulate in both fresh and marine waters under strong reducing conditions. The organic material is probably supplied in part as humus which is transported and deposited with the silts and clays. The chief source, however, is from various forms of plant and animal life which flourish in shallow waters and in the surface waters of lakes and oceans. As these forms die their remains settle below water level. Where water movements are rapid, sufficient oxygen is generally supplied to produce complete chemical decomposition of this organic material. However, in protected places, such as shallow lagoons or sheltered bays, wave and current action is

[1] Harder, E. C., U. S. Geol. Survey, Prof. Paper 113, pp. 68, 82-84, 1919.

slight and the waters become stagnant. Insufficient oxygen is present in the water to permit complete decomposition and at the same time the waters become highly charged with the products of organic decay. Under such environmental conditions putrifaction is retarded, the organic compounds tend to be broken up and deoxidized, and the volatile constituents tend to be emitted. Burial of the partly decomposed organic material in the accumulating silts and later changes attending consolidation of the mass produce the carbonaceous shale.

Micaceous Shale

Shale is generally said to be micaceous when the colorless or white mica is a conspicuous constituent. The mica occurs as small scale-like cleavage pieces with the flat surfaces generally parallel to the planes of lamination. The high reflection of light from the cleavage surfaces of the mica gives a light, shimmering appearance to the bedding surfaces of the shale. The white or colorless mica is widely distributed in shale as it is found in varying amounts in nearly all kinds. It is present as a primary mineral in igneous rocks; and it is especially abundant in such metamorphic types as gneiss, schist, and slate. It is not readily decomposed under ordinary conditions of weathering. The disintegrated particles resulting from the weathering process are readily transported in suspension and are deposited with the insoluble and unaltered products of rock decay. Micaceous shale varies widely in chemical composition and general appearance as it may also be arenaceous, ferruginous, calcareous, or carbonaceous in character.

Shales showing a wide range in chemical composition and physical properties occur in the rock outcrops of Ohio. The highly carbonaceous variety is well represented in the Ohio shale of Devonian age, the Sunbury shale of Mississippian age, and many thin shales associated with coal beds in the Pennsylvanian and Permian systems. Highly ferruginous types are found in the Bedford formation of the Mississippian, in the upper half of the Conemaugh series, and in Permian beds. Shales occurring in the western half of the State are dominantly calcareous as are also those of the Monongahela series and of the Permian system in the southeastern part. The sandy or arenaceous varieties of average iron and organic content and of low calcium carbonate content are limited in their distribution for the most part to the Mississippian system and to the Pennsylvanian system below the Monongahela series.

CHAPTER II

SHALES OF OHIO

By R. E. Lamborn, Chester R. Austin, Downs Schaaf

The shales of ceramic value in Ohio are confined in their stratigraphic distribution chiefly to beds of the Devonian and Mississippian systems and the Pottsville, Allegheny, and lower half of the Conemaugh series of the Pennsylvanian system. As indicated on the geologic map, the areal distribution is limited chiefly therefore to a belt extending in a general northeast-southwest direction through east central Ohio from the Ohio River to Lake Erie and east to the state line from Jefferson, Columbiana, Mahoning, Trumbull, and Ashtabula counties. A large percentage of the ceramic plants of the State utilizing shale are located in this belt. Shales from the upper part of the Conemaugh series and from the Permian and Ordovician systems are used at a few localities as in Belmont, Washington, and Hamilton counties respectively, but their combined importance is small.

The utilization of Devonian shales is confined chiefly to Cleveland and the Lake shore as far east as Conneaut. Here the Chagrin division of the Ohio shale formation is the source of supply. Plants operating on shales of the Mississippian, Pottsville, Allegheny, and Conemaugh ages are widely distributed along the outcrops, but perhaps due to better transportation facilities or nearness to potential markets, they occur in greater number in the northeastern quarter of the State. Many shale beds are recognized in the Pennsylvanian system, some of which are used as sources of material at widely separated localities. The Clarion shales and Lower Freeport shales of the Allegheny series are the two most important beds from the standpoint of present utilization.

In the following pages the many shale beds of the State are described in stratigraphic order. The chemical analyses, physical properties, and results of other tests on thirty samples of shale collected by R. E. Lamborn of the Geological Survey of Ohio in 1929 are stated in appropriate place.

By permission of the National Bureau of Standards, tests of ten samples of shale secured by A. E. MacGee in 1926 and 1927 are also included.

ORDOVICIAN SYSTEM

The Ordovician or oldest group of rocks exposed at the surface in Ohio outcrops over a triangular-shaped area of about 3,261 square miles in the southwestern corner of the State. This area includes all of Brown, Clermont, Hamilton, Butler, and Warren counties, the western part of Adams, Highland, Clinton, Greene, and Clark counties, the southeastern part of Miami, and the southern portion of Montgomery and Preble counties. In a structural sense this area extends across the crest of the Cincinnati geanticline, which in its formation has caused the beds to stand at higher levels than they occur to the eastward in Ohio. The Ohio River in turn has cut its channel across this axis and exposed many of the Ordovician formations. The oldest formation exposed, the Cynthiana, appears a little above river level in Brown, Clermont, and southeastern Hamilton counties, whereas the younger formations outcrop successively northward along the valleys tributary to the Ohio. The total thickness of the formations exposed is over 700 feet. The major subdivisions of the Ordovician system of Ohio with the general characteristics of each are given in the following table, the oldest appearing at the bottom and the youngest at the top:

Classification of the Ordovician System in Ohio

Subdivision	Group	General Description	Thickness in Ft. (Approx.)
Upper Ordovician or Cincinnatian	Richmond	Shale, bluish, interbedded with thin impure limestone.	215 to 265
	Maysville	Shale, bluish, with thin limestone.	130 to 240
	Eden	Shale, blue, with some limestone.	180 to 250
Middle Ordovician	Cynthiana	Limestone, with some shale.	100

As described in the preceding table, the rocks of the Ordovician system consist chiefly of shale and limestone interstratified. The limestone is of a bluish to buff color, generally thin bedded, and highly fossiliferous.[1] In some localities the layers are irregular and nodular in appearance. The interbedded shale, which makes up at least 50 per cent of the system in the Cincinnati region, is chiefly of the soft bluish variety and is generally highly calcareous.

The Ordovician shales have not been utilized for ceramic purposes to any great extent in Ohio as the lime content is generally too high to yield the best results and as the numerous layers of interstratified limestone are a detriment in the working of the beds. The only place in Ohio where shale of this age is utilized is at the plant of the Queen City Brick Co., at Cincinnati. This plant, which is located at Fairmount, utilizes shale of the Eden group for the manufacture of brick. A description of the exposures in the pit is given on the following page.

[1] Fenneman, N. M., Geol. Survey Ohio, 4th Ser., Bull. 19, pp. 55-70, 1916.

	Ft.	In.
Shale, bluish gray, calcareous, with some limestone. The limestone is thin bedded and occurs in zones 4 to 12 inches in thickness separated by 5 to 10 feet of shale	44	0
Shale, bluish gray, calcareous. Limestone layers generally wanting	33	0
Bottom of pit.		

The material is worked by steam shovel, the limestone blocks in large part being removed by hand. A sample of shale from this pit was collected by A. E. MacGee of the National Bureau of Standards.

Sample No. 200.

Tests of Eden shale from the pit of Queen City Brick Company, Cincinnati, Hamilton County. (Tests by National Bureau of Standards.)[1]

Chemical analysis		*Oxide ratio*					
Loss on ignition	6.5						
Silica, SiO_2	53.6						
Alumina, Al_2O_3	16.0						
Ferric oxide, Fe_2O_3	7.6						
Lime, CaO	6.5	K_2O	0.23				
Magnesia, MgO	2.9	Na_2O	0.05			SiO_2	3.35
Titanic oxide, TiO_2	1.0	CaO	0.41	Al_2O_3	1.00	TiO_2	0.06
Sodium oxide, Na_2O	0.9	MgO	0.18				
Potassium oxide, K_2O	3.7	FeO	0.43				
Sulphur, S	0.4						
Total carbon, C	1.1	RO	1.30				

Physical tests

Tempering water:	About 26 per cent
Drying linear shrinkage:	About 6 per cent
Drying volume shrinkage:	About 20 per cent

Burning Behavior

Burning temperature	Linear shrinkage Per Cent	Volume shrinkage Per Cent	Volume absorption Per Cent	Color
Cone 08	2.8	8.3	14.7	Light red
Cone 06	5.2	14.7	10.5	Light red
Cone 04	6.0	16.9	5.1	Gray buff
Cone 1	3.0	8.7	0.8	Gray with white lime pops

Overburning temperature: Cone 2 (1,135°C or 2,075°F.).

Best apparent burning range: Cone 04 to cone 01 (1,050°C. to 1,110°C. or 1,922°F. to 2,030°F.).

Total linear shrinkage at cone 04: About 12 per cent.

Deformation temperature: Cone 3 (1,145°C. or 2,093°F.).

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

SILURIAN SYSTEM

Beds of Silurian age and the Monroe series, as shown on the Geologic map of Ohio (1920), occur immediately below the glacial drift over an area of 11,338 square miles in the western half of Ohio. As the upper part of the Monroe series is now considered to be Devonian in age, the true area is slightly less than the figure given. The base of the Silurian system lies disconformably on the top of the Ordovician previously described. Rocks of the Silurian system occur immediately below the drift over the crest and upper flanks of the Cincinnati geanticline from Miami County north to the shore of Lake Erie near Toledo. The eastern border of the belt of exposures may be represented by a line extending from Sandusky on the north to the eastern part of Adams County on the south and the western border, crescent-shaped in outline, passes through Lucas, Wood, Henry, Putnam, and Paulding counties. The system is best developed in northern Ohio, where its thickness approaches 700 feet. It thins to the south along the belt of outcrop as the Monroe series thins and finally disappears from the section. In southern Adams County the Silurian system has a thickness of about 300 feet. The chief subdivisions with the character of the beds and approximate thickness of each subdivision are given in the following table of classification:

Classification of the Silurian System in Ohio

Subdivision	Group or Formation	General Description	Thickness Feet (Approx.)
Upper Silurian	Bass Island	Dolomite, drab, thin to thick bedded, with some shale	0 to 300
Middle Silurian	Niagara	Dolomite, thin to thick bedded	25 to 200
	Crab Orchard	Shale, calcareous, with some limestone beds, including the Dayton limestone in the lower part	10 to 100
Lower Silurian	Brassfield	Limestone, light colored, irregularly bedded	10 to 50

The Crab Orchard shale is the only shale of any stratigraphic importance occurring in the Silurian system of Ohio. This shale is highly calcareous in composition and therefore not well adapted to the manufacture of ceramic products. To the writer's knowledge shale of the Silurian system has never been utilized in Ohio for the production of brick or tile.

DEVONIAN SYSTEM

Rocks of Devonian age outcrop in three areas in Ohio which are separated from each other by Silurian exposures. The first and smallest occurs as an outlier near the crest of the Cincinnati axis in Logan and Champaign counties and is known as the Bellefontaine outlier. It has an area of approximately 118 square miles. The second region of Devonian outcrops is found in northwestern Ohio on the west flank of the Cincinnati axis and embraces an area of 1,388 square miles in Lucas, Wood, Henry, Paulding, Putnam, Defiance, Williams, and Fulton counties. The third and largest area occurs as a belt of outcrops of varying width on the eastern flank of the Cincinnati axis extending from eastern Adams County on the south to Sandusky County on the north and then northeastward along the southern shore of Lake Erie to the State line. The total area of this belt is about 4,274 square miles.

The beds of Devonian age in Ohio are composed of dolomites, dolomitic limestones, limestones, shales, and sandstones. The limestone and dolomite, which have a combined thickness of about 135 feet in central Ohio, are at the base of the series and outcrop over a belt extending from Sandusky, Erie County, to Deer Creek, Pickaway County. These beds are well known for the stone is quarried at many localities along the outcrop for economic purposes. The upper part of the Devonian consists of black carbonaceous shale and bluish gray arenaceous shale. The total thickness of the Devonian beds in Ohio is somewhat variable. In general, the greatest thickness is found in the northern part of the State. In Adams County, where the group is composed entirely of shale, the thickness ranges from 275 to 350 feet whereas in Erie County the total thickness, including dolomite, limestone, and shale, is in excess of 600 feet. From central Erie County eastward to the State line only the upper part of the system is exposed at the surface. The subdivisions of the Devonian system of Ohio with the character and variations in thickness on the outcrop are stated in the following table, the oldest appearing at the bottom and the youngest at the top.

Classification of the Devonian System in Ohio

Subdivision	Formation	General Description	Thickness in Feet (Approx.)
Upper Devonian	Ohio	Shale, black carbonaceous with some gray shale	275 to 600
	Olentangy	Shale, bluish gray, with some limestone	0 to 60
Middle Devonian	Delaware	Limestone, thin-bedded	0 to 40
	Columbus	Limestone and dolomite, thin-bedded to massive	0 to 110
Lower Devonian	Detroit River	Dolomite, drab, thin to thick-bedded	0 to 200
	Sylvania	Sandstone	0 to 25

The Ohio and so-called Olentangy shales are the only formations in the Devonian system which have any possibilities as sources of material for the production of brick and tile.

Olentangy Shale

The so-called Olentangy shale is a thin formation of bluish gray shale lying at the base of the black Ohio shale and having a thickness at the type locality at Delaware, Delaware County, of about 30 feet. This shale bed is regularly present in Franklin and Delaware counties in the central part of the State, and shale similar lithologically to the Olentangy is found below the black Ohio shale in some localities in Adams, Highland, and Ross counties in the southern part of the State. The writer believes that this gray shale in central and southern Ohio is a basal phase of the Ohio shale and should be considered as a member of that formation.[1] Its lithological characteristics, however, are different from those of the Ohio shale and, therefore, for ease of discussion in these pages it will be considered as a separate unit.

Where typically developed, the so-called Olentangy is a soft, bluish-gray clay shale which crumbles easily on exposure to the weather. Little, if any, lamination can be seen in this shale and when the mass crumbles it first tends to break up into small lens-shaped pieces which finally soften and pass into a blue clay. Impure limestone is often present in the shale either in the form of small flat, disc-like concretions arranged along certain zones or as thin layers passing through the mass. Pyrite is an ever-present impurity in the shale for it may be found at almost any exposure either in the form of small nodular concretions or as small grains or crystals scattered abundantly through the mass. Both the limestone and pyrite tend to lower the quality of the shale for ceramic purposes.

The Olentangy shale is generally present on the outcrop in southern Ohio as evidenced by exposures in western Ross, eastern Highland, and eastern Adams counties. In Adams and Highland counties the bed is marked by many thin layers of black, carbonaceous shale interstratified with the blue shale, and these black layers become more conspicuous to the southward. The thickness of the bed varies from 0 to about 60 feet, but the average of a number of measurements is about 34 feet.

The following section shows the character and thickness of the Olentangy shale exposed along Sulphur Creek located about 3½ miles southeast of Rome in Green Township, Adams County.[2]

[1] Lamborn, R. E., Jour. Geology, Vol. 35, pp. 708-722, 1927.

[2] Lamborn, R. E., Notes on Character and Occurrence of the Olentangy Shale in Southern Ohio, Ohio Jour. Sci., Vol. XXIX, p. 37, 1929.

	Ft.	In.
Ohio shale		
Black, carbonaceous shale with a few large spherical concretions..	52	0
Olentangy shale		
Blue clay shale with a few thin layers of black shale	10	6
Black, carbonaceous shale	..	5
Bluish-gray clay shale	..	9
Black, carbonaceous shale	2	6
Blue clay shale	..	6
Black, carbonaceous, and arenaceous shale	..	9
Blue clay shale	1	0
Brown shale	..	3
Blue clay shale	2	6
Covered interval	18	0
Monroe dolomite		
Hard, blue dolomite	4	0

The blue shale exposed at this locality was sampled by the writer in 1920 and analyzed by D. J. Demorest. The composition is as follows:

Chemical analysis

Loss at 105°C.	1.07
Ignition loss	6.26
Silica, SiO_2	63.11
Alumina, Al_2O_3	16.57
Titanic oxide, TiO_2	0.96
Phosphorus pentoxide, P_2O_5	0.11
Ferric oxide, Fe_2O_3	5.12
Lime, CaO	0.98
Magnesia, MgO	1.17
Sodium oxide, Na_2O	0.52
Potassium oxide, K_2O	4.44
Manganese oxide, MnO	0.01
Sulphur	1.47
Total carbon, C	0.89
Inorganic carbon, C	0.09

Percentage oxide ratio

$$\left.\begin{array}{ll} K_2O & .268 \\ Na_2O & .031 \\ CaO & .059 \\ MgO & .070 \\ FeO & .278 \\ MnO & .001 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.809 \\ TiO_2 & .058 \\ P_2O_5 & .006 \end{array}\right.$$

$$RO \quad .707$$

The Olentangy shale is exposed at a number of localities in Meigs and Franklin townships, Adams County, and in Brush Creek Township, Highland County. About seven-eighths of a mile southwest of Slate Hill in Brush Creek Township, the Olentangy shale has the character and thickness shown in the following section:[1]

[1] Lamborn, R. E., Notes on Character and Occurrence of the Olentangy Shale in Southern Ohio, Ohio Jour. Sci., Vol. XXIX, p. 31, 1929.

	Ft.	In.
Ohio shale		
Black, fissile carbonaceous shale	30	0
Olentangy shale		
Bluish gray, clay shale, weathering to a red clay	5	0
Covered interval	13	0
Blue clay shale	10	0
Covered interval	6	2
Niagara dolomite		
Dolomite	5	0

A part of the Olentangy formation is also well shown along Buckskin Creek about 2½ miles northwest of Bainbridge in the southwestern part of Ross Township, where the section is as follows.[1]

	Ft.	In.
Ohio shale		
Black carbonaceous shale	3	0
Olentangy shale		
Soft blue shale, weathering easily to a blue mud	6	2
Irregular layer of blue limestone	..	4
Light blue clay shale	2	2
Dark blue clay shale	2	0
Covered interval	21	0
Monroe dolomite		
Dolomite	5	0

A sample of the blue shale collected by the writer at the above locality in 1920 was analyzed by D. J. Demorest. The results of this analysis are as follows:

Chemical analysis

Loss at 105 ° C.	0.03
Ignition loss	7.14
Silica, SiO_2	63.03
Alumina, Al_2O_3	16.56
Titanic oxide, TiO_2	0.88
Phosphorus pentoxide, P_2O_5	0.10
Ferric oxide, Fe_2O_3	5.62
Lime, CaO	1.10
Magnesia, MgO	1.56
Sodium oxide, Na_2O	0.40
Potassium oxide, K_2O	4.05
Manganese oxide, MnO	0.06
Sulphur, S	1.16
Total carbon, C	1.08
Inorganic carbon, C	0.51

Percentage oxide ratio

$$\left.\begin{array}{ll} K_2O & .245 \\ Na_2O & .024 \\ CaO & .066 \\ MgO & .094 \\ FeO & .305 \\ MnO & .004 \\ & \overline{} \\ RO & .738 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.806 \\ TiO_2 & .053 \\ P_2O_5 & .006 \end{array}\right.$$

In Fayette, Pickaway, and the southern half of Franklin County, the horizon of the Olentangy shale is covered with a thick mantle of glacial

[1] Lamborn, R. E., Notes on Character and Occurrence of the Olentangy Shale in Southern Ohio, Ohio Jour. Sci., Vol. XXIX, pp. 29–30, 1929.

drift and, therefore, the character and thickness of the formation in this area are not known. North of Columbus this shale is exposed at a number of localities along the Olentangy River and its tributaries in Franklin and Delaware counties, where it has a thickness ranging from 23 to 40 feet. The character of the formation is similar to the shale exposed in southern Ohio with the exception that limestone nodules and layers are more numerous and the zones of interstratified black shale are thinner and less frequent. A section of the shale measured near Delaware, Delaware County, is as follows:[1]

	Ft.	In.
Ohio shale		
Badly weathered and much altered black shale	8	0
Black shale with some large more or less spherical concretions and some thin arenaceous layers at the contact below	22	0
Olentangy shale		
Soft, blue, argillaceous shale	2	4
Horizon of discontinuous layer of flat blue limestone concretions	..	..
Soft, argillaceous, blue shale rock, a few thin layers of brown or black shale	5	4
Soft, argillaceous, blue limestone	..	4
Soft, blue shale	1	4
Brown to black shale with an occasional trail in it	..	4
Argillaceous, soft, blue shale	1	0
Layer of brown to black shale with blue trails	..	1
Argillaceous, soft blue shale	2	6
Layer of brown shale with markings of blue	..	1
Soft blue shale with a half-dozen or more thin layers of argillaceous, blue limestone, an occasional flat limestone concretion near the base	4	10
A persistent layer of flat limestone concretions	..	8
Soft, blue shale, with an occasional flat disc-like concretion	1	6
Persistent layer of disc-like concretions	..	4
Soft argillaceous, blue shale with several discontinuous layers of disc-like or flat concretions	3	0
Rather definite layers of flat, irregular limestone concretions	..	5
Soft argillaceous, blue shale with a few rather irregular blue limestone concretions	3	4
Argillaceous, blue limestone breaking with a very irregular and conchoidal fracture	..	4
Soft argillaceous, blue shales tending to be massive, to level of Olentangy River	..	4

The Olentangy shale was formerly worked to some extent by the National Fireproofing Company at Delaware, where it was mixed with the overlying Ohio shale and used for the manufacture of brick and hollow tile. A sample of the shale at this place shows the following composition.[2]

[1] Stauffer, C. R., Geol. Survey Ohio, 4th Ser., Bull. 10, pp. 88-89, 1909.
[2] Westgate, L. G., Geol. Survey Ohio, 4th Ser., Bull. 30, pp. 81, 82, 1926.

Chemical analysis

Loss at 105°C	1.21
Ignition loss	8.02
Silica, SiO_2	57.22
Alumina, Al_2O_3	16.15
Titanic oxide, TiO_2	1.26
Phosphorus pentoxide, P_2O_5	0.099
Ferric oxide, Fe_2O_3	4.78
Lime, CaO	3.71
Magnesia, MgO	2.31
Sodium oxide, Na_2O	0.16
Potassium oxide, K_2O	3.86
Manganous oxide, MnO	0.016
Sulphur, S	0.96
Total carbon, C	1.69
Inorganic carbon, C	1.00

Percentage oxide ratio

K_2O	.239	Al_2O_3	1.00	SiO_2	3.530
Na_2O	.010			TiO_2	.078
CaO	.229			P_2O_5	.006
MgO	.143				
FeO	.266				
MnO	.001				
RO	.888				

A microscopic examination of this shale was made by W. J. McCaughey who reported as follows:[1]

"When moistened with water and rubbed with the thumb to disintegrate and deflocculate the mass, the Olentangy shale gives in water a gray, silvery suspension somewhat similar to that of fine-grained mica or to that of crystalline kaolinite in water. Silky suspensions are also produced in fine-grained crystalline precipitates and are probably due to the reflection of light from the faces of the crystals.

"The sample was separated by deflocculation and decantation to yield a sand separate, two silt separates, and a clay separate, which were examined separately.

"The sand separate was small in amount, a percent or two, and consisted predominantly of a carbonate mineral of the calcite series, generally in rhombohedral crystals. The index of refraction of the ordinary ray of this mineral was slightly less than 1.680 which indicates that the mineral has a composition rather close to dolomite.

"The rhombohedral aspect of the crystals is also a characteristic habit of dolomite. Sometimes this dolomite is a fine-grained aggregate often with nearly parallel orientation. In the heart of the dolomite particles is a core of pyrite generally in tiny crystals (cubes and cubes modified by octahedrons). Pyrite also occurs free as crystals. A smaller amount of quartz is present and occasionally a cleavage fragment of muscovite.

"The silt separate forms a large part of the sample and carries abundant dolomite grains as rhombohedral crystals and as separate grains composed of aggregates of finer crystals of dolomite. A fairly large amount of muscovite and sericite is present. Pyrite is also found in considerable amount either as separate crystals or imbedded in or attached to dolomite. In smaller amount, well-rounded and clear fragments of primary quartz occur, though most of the quartz is present as a very fine-grained mineral free or imbedded in a sericite-clay-quartz aggregate.

"The dolomite is generally free as rhombohedral fragments, sometimes attached to the clay aggregates but not frequently enclosed in them. The clay aggregates, though generally free from enclosed dolomite, carry abundant inclu-

[1] Idem, pp. 32-33.

sions of sericite and fine-grained quartz; also in smaller amount rutile as very tiny needles; and tiny rounded particles, more or less opaque and difficult of determination—probably iron oxide or partially oxidized pyrite.

"Rarely grains of tourmaline and still more rarely zircon and rutile are found. An occasional grain of biotite is present, stained red by iron oxide.

"The clay separate is a fine-grained aggregate composed of kaolin with abundant sericite and finely divided quartz and a much smaller amount of rutile as tiny needles.

"The minerals, as separate grains of the Olentangy shale, in order of their abundance are dolomite, pyrite, sericite, quartz, and muscovite; more rarely tourmaline, biotite, zircon, and rutile. In the clay aggregates the minerals are kaolin, sericite, quartz, and rutile.

"An outstanding characteristic of the sample lies in the large amount of free (unattached) crystals of dolomite and of pyrite, the latter often enclosed in the dolomite or attached to it. A large part of the quartz is very finely divided and is present in the clay aggregate. The high content of sericite is noteworthy and the comparative freedom of the small clay aggregates (broken in preparation of sample) from dolomite.

"The silky character of the suspension of the Olentangy shale is probably due to the presence of the minute and free crystals of dolomite and to sericite and muscovite held in water suspension."

North of Delaware County very little is known about the Olentangy shale as the region where it should outcrop is covered with a thick coating of glacial drift.

Economic Value

As a source for ceramic products such as brick and tile, the Olentangy shale ranks low. Visible impurities such as lime nodules and pyrite concretions are plentiful and harmful ingredients. Furthermore, the presence of interstratified black shale, which can not be separated economically in the working of the deposit, increases the carbon content and leads to difficulties in firing.

The Olentangy shale is not utilized at any place in Ohio for the manufacture of ceramic products.

Ohio Shale

The Ohio shale, which makes up a large fraction of the Devonian system, outcrops over a belt varying from two to thirty miles in width extending from Adams County on the south to Erie County on the north and thence east along the southern shore of Lake Erie to the Pennsylvania State line. The thickness of this shale is variable for it measures 275 to 300 feet in Adams County, about 300 feet in Pike County, some 600 feet in Franklin County, and about 450 feet in Erie County. East from Erie County the shale increases in thickness, reaching a figure as great as 2,300 feet at Cortland, Trumbull County, where the formation has been penetrated in drilling for oil and gas.

Throughout central and southern Ohio the Ohio shale formation is dominantly a black or dark brown carbonaceous and somewhat arenaceous shale which splits up rather readily into thin slate-like slabs or pieces. On prolonged exposure to the weather it changes to a grayish color. Where steep, cliff-like exposures occur, the numerous joint planes are often stained a reddish or brownish tint with iron oxide. In general, the percentage of organic material in the shale is sufficiently high to support combustion if the rock is once heated to the kindling temperature. Throughout the regions of outcrop in central and southern Ohio, beds of gray, somewhat arenaceous shale appear interstratified with the black variety. These gray zones are apparently local in distribution and seem to appear at different stratigraphic horizons, although they are more prevalent in the lower half of the formation.

The presence of concretions is a noticeable feature of the Ohio shale. The most conspicuous forms occur as large spherical or nearly spherical masses, often several feet in diameter, so formed that the planes of lamination of the black shale in which they are always embedded bend above and below the concretion. These bodies are composed chiefly of calcium and magnesium carbonates with minor amounts of iron compounds and clay. Pyrite in concretionary forms or as finely disseminated material is present in considerable quantities. The Ohio shale has never been utilized for the manufacture of ceramic products in Ohio south of Franklin County. At Columbus the black shale of this formation mixed with a small percentage of glacial drift was formerly used for the manufacture of sewer pipe by the Columbus Sewer Pipe Company with fair results.

An analysis of an average sample of the shale used at this plant is given below. William McPherson, analyst.[1]

Chemical analysis

Silica SiO_2	58.38
Alumina Al_2O_3	20.89
Water (combined) H_2O	7.53
Ferric oxide Fe_2O_3	5.78
Lime, CaO	0.44
Magnesia MgO	1.57
Potash K_2O	4.68
Soda Na_2O	0.34
	99.61
Fluxing impurities	12.81
Clay and sandy impurities	86.80

Up until 1928 the Shale Brick Company of Columbus worked a blue shale bed of the Ohio formation for the manufacture of common brick. Due to a shortage of available shale, the practice was changed and glacial drift is now being utilized. The black Ohio shale was also formerly

[1] (Geol. Survey Ohio, Vol. VII, Part I, page 133, 1893).

used in a small way by the National Fireproofing Company at Delaware where it was mixed with the Olentangy shale and manufactured into hollow tile.

From Delaware County north through Marion, Morrow, Crawford, Huron, and Seneca counties, the region of outcrops of Ohio shale is covered with a thick mantle of glacial drift and, therefore, little is known about the formation. In northern Ohio, which includes the outcrops from Erie County east to Pennsylvania State line, the Ohio shale formation has been divided into three parts as follows: Cleveland shale, Chagrin shale, Huron shale.

The Cleveland and Huron shales, which form respectively the top and bottom of the series, are alike lithologically, and in all their apparent characteristics are like the black Ohio shale of central and southern Ohio. The Chagrin shale, on the other hand, resembles the bluish-gray beds of Ohio shale in the Columbus area, but tends to be more sandy or arenaceous in character.

The Cleveland and Huron shales have received little attention in northern Ohio as sources of material for ceramic products, but the Chagrin shale has been utilized at a number of places at Cleveland and along the Lake front as far as Conneaut.

The Chagrin shale is the chief source of material at the Warner plant of the Cleveland Builders Supply & Brick Company and at the plant of the Ohio Clay Company, both located near the mouth of Mill Creek just south of Cleveland. These plants produce face brick. At the plant of the Cleveland Brick and Clay Company, the Chagrin shale is used extensively for the manufacture of paving brick. The capacity of the plant is about 45,000 brick a day. The rock exposures at the pit are described below:

		Ft.	In.
Shale, reddish brown	*Bedford*	3	0
Covered interval	*Bedford*	6	0
Sandstone, brown, thin-bedded	*Bedford*	5	0
Shale, soft, bluish-gray	*Bedford*	5	0
Shale, black carbonaceous, *Cleveland*		42	0
Shale, grayish blue, a little sandy	*Chagrin*	38	3
Shale, hard, grayish blue, sandy	*Chagrin*	1	3
Shale, grayish blue, a litle sandy	*Chagrin*	31	6

The Chagrin shale is used exclusively in this plant. A sample of the Chagrin exposed in the pit was cut on August 14, 1929, and was submitted for testing. The results are stated on the following page.

Sample No. 47

Tests of Chagrin shale from pit of Cleveland Brick & Clay Co., Cleveland, Cuyahoga County

Chemical analysis

Water, hydroscopic, H_2O —	1.50
Water, combined, H_2O + ...	5.11
Silica, SiO_2	59.56
Alumina, Al_2O_3	15.90
Titanic oxide, TiO_2	1.05
Phosphorus pentoxide, P_2O_5.	.18
Ferric oxide, Fe_2O_3	5.72
Ferrous oxide, FeO	4.06
Lime, CaO	.62
Magnesia, MgO	.36
Sodium oxide, Na_2O	.42
Potassium oxide, K_2O	3.50
Manganese oxide, MnO	.04
Ferrous sulphide, FeS_2	.88
Carbon dioxide, CO_2	1.02
Carbon, organic, C	.27

Downs Schaaf, analyst

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .220 \\ Na_2O & .026 \\ CaO & .039 \\ MgO & .023 \\ FeO & .613 \\ MnO & .002 \\ \hline RO & .923 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.746 \\ TiO_2 & .066 \\ P_2O_5 & .011 \end{array}\right.$$

Physical properties, determined By Chester R. Austin

Properties in green state

Workability: This material has rather short plasticity. A badly featheredged column is extruded from the die.

Time of slaking: 58.40 minutes

Water of plasticity: 17.77 per cent

Dry shrinkage

Volume: 10.03 per cent

Linear: 3.24 per cent

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 304 pounds per square inch

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
012	27.44	1.41 +	0.47 +	14.60	1.88	2.59
010	25.90	0.66	0.22	13.40	1.93	2.59
08	21.33	7.35	2.4	10.40	2.05	2.60
06	13.31	13.62	4.3	6.08	2.19	2.52
04	6.85	17.30	5.5	6.98	2.29	2.45
02	5.23	17.69	4.8	2.27	2.30	2.42
1	3.61	18.09	5.7	1.55	2.30	2.41

Fired modulus of rupture:

Cone 08, 2,036 pounds per square inch.

Cone 04, 3,526 pounds per square inch.

Fired specific impact strength:

Cone 05, 1.41 centimeter kilograms per square centimeter.

Cone 09, 1.17 centimeter kilograms per square centimeter.

Fired crushing strength:
Cone 04, 12,626 pounds per square inch.
Best firing range: Cone 010 to cone 02.
Overfiring temperature: Cone 1.
Pyrometric cone equivalent: Cone 11-12.
Scumming: Scumming takes place throughout the entire firing range of this material. Six pounds of $BaCo_3$ per ton of material is necessary to prevent scumming.
Salt glazing: This material does not withstand the temperature necessary for the formation of a good salt glaze.
Utilization: This shale was being used for the production of paving brick. Other possibilities for utilization consist of face brick and common brick. The fired material has a somewhat stony structure. A good red color is developed at cone 02.

The Chagrin shale has been used extensively at Collinwood by the Collinwood Shale Brick & Supply Company for the manufacture of paving brick and sewer block. The shale utilized has a thickness of about 80 feet. It is a fine-grained shale of a bluish-gray color and is remarkably uniform throughout the exposure. It is mined by means of a shale planer which extends across the entire thickness of the exposure. A sample of the shale was taken directly from the planer by A. E. MacGee of the National Bureau of Standards.

Sample No. 201

Tests of the Chagrin shale from the pit of the Collinwood Shale Brick & Supply Company, Collinwood Station, Cleveland, Cuyahoga County. Tests by the Bureau of Standards.[1]

Chemical analysis		*Oxide ratio*					
Loss on ignition	6.0						
Silica, SiO_2	57.1						
Alumina, Al_2O_3	19.6						
Ferric oxide, Fe_2O_3	8.0	K_2O	.19				
Lime, CaO	0.6	Na_2O	.03			SiO_2	2.91
Magnesia, MgO	1.8	CaO	.03	Al_2O_3	1.00	TiO_2	0.05
Titanic oxide, TiO_2	1.0	MgO	.09				
Sodium oxide, Na_2O	0.7	FeO	.37				
Potassium oxide, K_2O	3.7						
Sulphur, S	0.8	RO	.71				
Total carbon, C	0.6						

Physical tests

Tempering water:	About 20 per cent
Drying linear shrinkage:	About 4 to 5 per cent
Drying volume shrinkage:	About 14 to 15 per cent

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	2.8	8.2	12.3	Buff
Cone 06	4.7	13.5	7.5	Red orange
Cone 04	7.2	20.2	4.7	Tan
Cone 03	5.9	16.7	5.1	Gray
Cone 02	6.4	18.0	2.8	Grayish brown
Cone 01	6.6	18.6	2.1	Gray black
Cone 1	7.3	20.4	2.1	Good red, flashes readily

Overburning temperature: About cone 2 (1,135° C. or 2,075° F.).
Best apparent burning range: Cone 06 to cone 01 (1,005°C. to 1,110°C. or 1,841°F. to 2,030°F.).
Total linear shrinkage at cone 1: About 12 per cent.
Deformation temperature: Cone 10 (1,260°C. or 2,300°F.).

At Wickliffe, near the western edge of Lake County, the Buckeye Shale Brick Company utilizes the Chagrin shale for paving brick. Material from this formation was also formerly used for paving brick by the Zanesville Clay Products Company at its plant located near Conneaut, Ashtabula County. A description of the exposures of Chagrin shale at the pit of the Graham Clay Products of Conneaut is as follows:

	Ft.	In.
Glacial drift, sandy	12	0
Shale, bluish gray, some layers are very sandy, *Chagrin*	21	0

Both the Chagrin shale and overlying glacial drift are used at this plant for hollow tile and brick. The relative amounts of the two materials used are in the proportions as delivered by the shovel. The Chagrin shale from this locality was sampled on August 16, 1929, and the sample was submitted for testing. The results of the various tests are listed below:

Sample No. 48

Tests of Chagrin Shale from pit of Graham Clay Products Co., Conneaut, Ashtabula County

Chemical analysis

Downs Schaaf, analyst

Water, hydroscopic, H_2O-	1.41
Water, combined, H_2O+	5.50
Silica, SiO_2	59.40
Alumina, Al_2O_3	18.14
Titanic oxide, TiO_2	0.80
Phosphorus pentoxide, P_2O_5	0.22
Ferric oxide, Fe_2O_3	3.08
Ferrous oxide, FeO	3.14
Lime, CaO	1.90
Magnesia, MgO	1.72

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .111 \\ Na_2O & .019 \\ CaO & .104 \\ MgO & .095 \\ FeO & .326 \\ MnO & .002 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.275 \\ TiO_2 & 0.044 \\ P_2O_5 & 0.012 \end{array}\right.$$

$$\begin{array}{ll} RO & .657 \end{array}$$

Chemical analysis, continued

Sodium oxide, Na_2O........	0.35
Potassium oxide, K_2O......	2.01
Manganese oxide, MnO.....	0.04
Sulphur trioxide, SO_3......	1.45
Ferrous sulphide, FeS_2......	0.24
Carbon dioxide, CO_2........	0.52
Carbon, organic, C.........	0.27

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has good plasticity. A good column is extruded from the die.

Time of slaking: 10.38 minutes.

Water of plasticity: 21.07 per cent.

Dry shrinkage:

Volume: 11.44 per cent.

Linear: 3.68 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 297 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	23.18	10.88	3.5	11.64	1.99	2.60
04	15.13	17.45	5.5	7.03	2.14	2.53
02	12.90	19.53	6.1	5.89	2.19	2.53
1	10.61	21.47	6.7	4.70	2.26	2.53
3	8.02	21.32	6.6	3.50	2.27	2.46
5	5.17	19.20	6.0	2.35	2.20	2.32
7	22.39	9.72+	3.1+	17.30	1.30	1.67

Fired modulus of rupture:

Cone 05, 2,761 pounds per square inch.
Cone 3, 3,470 pounds per square inch.

Fired specific impact strength:

Cone 05, 1.42 centimeter kilograms per square centimeter.
Cone 3, 1.16 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 3, 7,044 pounds per square inch.

Best firing range: Cone 06 to cone 5.

Overfiring temperature: Cone 7.

Pyrometric cone equivalent: Cone 8-9.

Scumming: Scum occurs on all trials fired to cone 5 and lower. Six pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: This material does not withstand the temperature necessary for the development of a good salt glaze.

Utilization: This shale was being used for the production of hollow tile. It can be utilized also for the manufacture of face brick, common brick, and drain tile. The fired material develops a good red color at cone 02.

Other Analyses of Ohio Shale from the Cleveland District[1]

	1	2	3	4	5	6
Silica, SiO_2	58.71	56.40	57.80	61.20	61.90	62.60
Alumina, Al_2O_3	21.90	23.02	21.11	19.21	21.55	21.10
Iron oxide, Fe_2O_3	4.55	4.50	5.80	4.55	4.25	4.40
Magnesia, MgO	2.00	1.64	1.73	1.46	1.44	1.40
Lime, CaO	1.67	0.85	0.80	2.00	1.50	1.54
Soda, Na_2O / Potash, K_2O	....	....	2.95	....	....	....
Combined water, H_2O	6.64	5.91	6.01	9.13	4.96	4.12
Sulphur trioxide, SO_3	2.57	0.86	1.22	0.43	0.20	1.05
Carbon, C	.00	.00	.00	.00	.00	.00
	98.04	93.18	97.42	97.98	95.80	96.21

	7	8	9	10	11	12	13
Silica, SiO_2	59.35	55.13	60.26	59.85	56.10	58.10	55.10
Alumina, Al_2O_3	20.05	19.99	20.57	18.60	17.18	15.50	20.86
Iron oxide, Fe_2O_3	8.05	5.28	4.00	4.50	4.42	4.22	4.30
Magnesia, MgO	1.51	1.33	1.85	1.40	1.24	1.08	1.46
Lime, CaO	1.20	0.44	0.48	0.40	0.15	0.05	1.80
Soda, Na_2O / Potash, K_2O	4.11	3.37	....	....	2.67	2.91	....
Combined water, H_2O	5.30	6.66	3.34	6.23	6.49	7.02	7.30
Sulphur trioxide, SO_3	....	....	3.52	2.05	....	....	3.13
Carbon, C	0.40	7.14	4.47	3.93	11.01	10.50	5.85
	99.97	99.34	98.49	96.96	99.26	99.38	99.80

Nos. 1, 2—Chagrin shale, blue, Cleveland Brick and Clay Co., F. J. Peck and Co., analysts.

No. 3—Chagrin shale, blue, John Kline Brick Co., F. J. Peck and Co., analysts.

No. 4—Chagrin shale, brown, Newburg Brick and Clay Co., F. J. Peck and Co., analysts.

Nos. 5, 6—Chagrin shale, blue, Newburg Brick and Clay Co., F. J. Peck and Co., analysts.

No. 7—Chagrin shale, blue, Ohio Clay Co., Oscar Textor, analyst.

No. 8—Cleveland shale, black, Cleveland Brick and Clay Co., Oscar Textor, analyst.

Nos. 9, 10—Cleveland shale, black, Cleveland Brick and Clay Co., F. J. Peck and Co., analysts.

Nos. 11, 12—Cleveland shale, black, Brower farm, Ohio Clay Co., Oscar Textor, analyst.

No. 13—Cleveland shale, black, Newburg Brick and Clay Co., F. J. Peck and Co., analysts.

MISSISSIPPIAN SYSTEM

Rocks of Mississippian age in Ohio outcrop over a belt of varying width, extending from the Ohio River in Scioto County north to Huron County and then northeastward, meeting the Pennsylvania line in Trumbull and Ashtabula counties. This belt of outcrops has a width of 20 to 25 miles at its southern end, but its width increases to the north to as much as 50 miles as measured across Huron, Ashland, and Wayne counties. From this latter region the belt narrows to the eastward, in western Trumbull and eastern Geauga counties the zone of outcrops being not more than 5 miles in width. In the northwestern corner of the State, including parts of Williams, Defiance, and Fulton counties, the bedrock in contact with the glacial drift is of Mississippian age. The area in Ohio

[1] U. S. Geol. Survey, Bull 818, p. 106, 1931.

over which rocks of Mississippian age outcrop is about 8,586 square miles or a little more than 20 per cent of the area of the State.

The Mississipian rocks of Ohio, with the exception of the Maxville limestone, are of the clastic varieties such as shale, sandstone, and conglomerate. The sediments forming this series were originally deposited in shallow waters close to the shore. As a result of either a change in the position of the shore by earth movements or of marked changes in climatic conditions there was a frequent shifting of the zones of deposition in such a way that the sediments deposited and later consolidated into bedrock show marked variations in character in both a horizontal and vertical direction. For these reasons the characteristics of the group often show considerable change from one locality to another. The thickness of the group is also subject to much variation, due in part to difference in thickness of the sediments originally deposited and in part to the different amounts removed by erosion preceding Pennsylvanian time. In Scioto County, Stout estimates the total thickness to range between 600 to 800 feet.[1] The group apparently thickens to the north for in Ross and Vinton counties Hyde reports the Waverly series to be represented by about 1,000 feet of sandstone, shale, and conglomerate.[2] Estimates of the thickness of this group in Muskingum County, based on drillers' records, show variations ranging from 700 to 900 feet. In Wayne County, the maximum thickness approaches 1,000 feet.[3] In Cuyahoga County the thickness of the Mississippian approaches 550 feet at South Brooklyn[4] and Prosser reports a thickness of 323 feet along Brandywine Creek at the southern edge of the county.[5] At Gates Mills in the northeastern part of Cuyahoga County the thickness is about 288 feet, and along Phelps Creek in Ashtabula and Geauga counties it is 346 feet.[6] Due to the variable character of the Mississippian rocks, a detailed classification which is applicable to one section does not necessarily apply to a region remotely distant. In general the Mississippian of Ohio can be grouped into the following formations, the oldest appearing at the bottom and the youngest at the top of the list.

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[1] Geol. Survey Ohio, 4th Ser., Bull. 20, p. 469, 1916.
[2] Geol. Survey Ohio, 4th Ser., Bull. 31, p. 43, 1927.
[3] Geol. Survey Ohio, 4th Ser., Bull. 24, pp. 49-50, 1921.
[4] Geol. Survey Ohio, 4th Ser., Bull. 15, p. 33, 1912.
[5] Idem., p. 143.
[6] Idem., p. 194.

Classification of the Mississippian System of Ohio

Formation	General Description	Thickness in Ft. (Approx.)
Maxville	Limestone, light-colored, thin- to thick-bedded.	0- 50
Logan	Sandstone and shale.	200 ±
Cuyahoga	Shale and sandstone.	175-600
Sunbury	Shale, black, carbonaceous.	10- 40
Berea	Sandstone, gray, thin- to thick-bedded, medium-grained.	0-200
Bedford	Shale, dark-bluish gray and red in color, with some thin-bedded sandstone.	60- 90

Bedford Shale

The Bedford shale, which is the basal formation of the Mississippian group or system, outcrops in a belt extending entirely across the State from Adams to Erie counties and thence east to Cleveland. Throughout much of southern Ohio, including Adams, Pike, and Ross counties, the lower part of the formation consists of bluish-gray, arenaceous and calcareous shales. Higher in the formation thin layers of gray sandstone appear interstratified with the shale and these sandstone layers increase in number upward to such an extent that in Adams County there is no well-defined lithological line of separation between the Bedford and the overlying Berea formation. The thickness of the Bedford shale in Ross County is 80 to 90 feet.

North of Ross County the Bedford formation undergoes a change in lithology. The sandstone layers entirely disappear except at some localities at the very top of the formation; the shale becomes more argillaceous and calcareous; and the middle portion in many localities is a shale of a reddish-brown color. The red shales of the Bedford have been identified at various localities along its outcrop from Circleville, Pickaway County, to Cleveland, Cuyahoga County.

In Franklin County the Bedford formation consists of both the bluish-gray and reddish-brown varieties of shale. The outcrops extend in a general north-and-south direction through the eastern range of townships where the thickness of the formation varies from 60 to 90 feet. Its general features are shown in the following section of the exposures along Rocky Fork, in Jefferson Township, a short distance east of Gahanna.[1]

	Ft.	In.
Shale, soft, argillaceous, blue	38	8
Shale, soft, argillaceous, gray, mottled	8	0
Shale, soft, fissile, chocolate brown, weathers rapidly to a stiff, reddish clay	25	6
Shale, soft, argillaceous, blue, fissile and much jointed	15	6
Shale, argillaceous, blue, very fossiliferous, especially near base	2	0
Shale, dark bluish-brown, rather soft	..	4

[1] U. S. Geol. Survey, Geologic Atlas of United States, Columbus Folio, No. 197, p. 7, 1915.

Bedford shale has been utilized for a number of years for the production of face brick by the Claycraft Mining and Brick Company at Taylor, Jefferson Township, Franklin County. The shale, which is of the reddish-brown variety, has a thickness exposed in the pit of 25 to 40 feet, all of which is remarkably uniform in texture and appearance. A. E. MacGee of the National Bureau of Standards sampled the shales in this pit for testing.

Sample No. 202

Tests of Bedford shale from the pit of the Claycraft Mining & Brick Company, Taylor, Franklin County. (Tests by the National Bureau of Standards.)[1]

Chemical analysis

Loss on ignition	7.0
Silica, SiO_2	59.4
Alumina, Al_2O_3	17.2
Ferric oxide, Fe_2O_3	8.9
Lime, CaO	0.5
Magnesia, MgO	1.5
Titanic oxide, TiO_2	1.2
Sodium oxide, Na_2O	0.2
Potassium oxide, K_2O	2.9
Sulphur, S	0.0
Total carbon, C	0.6

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .17 \\ Na_2O & .01 \\ CaO & .03 \\ MgO & .09 \\ FeO & .46 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.45 \\ TiO_2 & 0.07 \end{array}\right.$$

RO .76

Physical tests

Tempering water:	About 20 per cent.
Drying linear shrinkage:	About 5 to 6 per cent.
Drying volume shrinkage:	About 17 to 18 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	1.3	3.9	11.4	Buff
Cone 06	4.1	11.8	7.9	Salmon
Cone 04	5.8	16.5	5.0	Tan
Cone 03	6.6	18.4	3.2	Gray
Cone 02	7.1	19.8	1.7	Brown
Cone 01	6.9	19.3	1.8	Dark red
Cone 1	6.5	18.3	1.2	Maroon flashes
Cone 4	6.4	17.9	0.6	Dark red
Cone 7	6.1	17.1	0.7	Maroon

Overburning temperature: About cone 8 (1,225°C. or 2,237°F.).
Best apparent burning range: Cone 06 to cone 1 (1,005°C. to 1,125°C. or 1,841°F. to 2,057°F.).
Total linear shrinkage at cone 02: About 12 to 13 per cent.
Deformation temperature: Cone 13 (1,350°C. or 2,462°F.).

In Delaware County the belt of outcrop of the Bedford shale follows along the eastern side of the valley of Big Walnut Creek through Genoa, Berkshire, and Kingston townships. The thickness of the formation, which consists of both the blue and gray varieties of shale, is about 60 feet. Since 1926 the Bedford shale has been used for the manufacture of drain tile by the Galena Shale Tile and Brick Company at Galena. A

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

sample of the shale at this place, analyzed by D. J. Demorest, has the following composition:[1]

Chemical analysis

Loss at 105°C	1.44
Ignition loss	6.46
Silica, SiO_2	57.76
Alumina, Al_2O_3	18.58
Titanic oxide, TiO_2	1.50
Phosphorus pentoxide, P_2O_5	0.114
Ferric oxide, Fe_2O_3	7.45
Lime, CaO	0.55
Magnesia, MgO	1.33
Sodium oxide, Na_2O	0.52
Potassium oxide, K_2O	3.51
Manganese oxide, MnO	0.018
Sulphur, S	0.029
Total carbon, C	0.71
Inorganic carbon, C	0.30

Percentage oxide ratio

K_2O	.189	Al_2O_3	1.00	SiO_2	3.115
Na_2O	.028			TiO_2	.081
CaO	.030			P_2O_5	.006
MgO	.071				
FeO	.362				
MnO	.001				
RO	.681				

A sample of the Bedford shale from Galena was submitted to W. J. McCaughey for microscopic examination. The results of this examination are stated below:[2]

"The sand and coarse silt separate contain abundant quartz and undisintegrated clay aggregates with a smaller amount of dolomite (index higher than 1.67) in aggregates, also muscovite, chlorite, sericite, and biotite (latter deep red or yellow in color). Tourmaline, zircon, and rutile are also present, but are not abundant.

"The finer silt and clay separate contain abundant sericite and quartz and a smaller amount of dolomite, the latter generally free or unattached. There is also present occasional cleavage flakes of muscovite, biotite, and chlorite.

"The clay is a quartz-sericite-kaolin aggregate carrying tiny needles of rutile and red to yellow particles of iron oxide. The abundant sericite in the clay aggregate and in the clay separate is noteworthy; also the constant association of bright green cleavage fragments of chlorite and the abundance of muscovite in the coarser separates.

"In the Bedford the quartz has a higher concentration in the coarse separates (sand and coarse silt) and occurs in much larger fragments than in the Olentangy examined. The Bedford contains more mica in larger cleavage fragments (muscovite, biotite, and chlorite), than was found in the Olentangy. The clay aggregate in the Bedford is more complex, mineralogically, and carries more iron oxide than the Olentangy.

"As separate grains, the minerals in the order of their abundance are quartz, sericite, dolomite, muscovite, chlorite (bright green flakes), biotite (somewhat altered, yellow or deep red), tourmaline, zircon, and rutile. In clay aggregates the minerals in order of their abundance are kaolin, sericite, quartz, iron oxide, and rutile."

[1] Geol. Survey Ohio, 4th Series, Bull. 30, p. 40, 1926.
[2] Idem., p. 40.

From Delaware County the belt of outcrops of Bedford shale extends northward through Morrow, Crawford, and Huron counties to eastern Erie County. Throughout this belt the thick deposit of glacial drift permits few bedrock exposures except along the Vermilion and Huron rivers and their branches. The Bedford is described along the Vermilion River Valley as a "bed of shale forty to sixty feet in thickness, which is sometimes blue or banded in color, but more generally red.[1]

In Lorain County the Bedford shales are known from exposures along the Vermilion River in Brownhelm Township, at the quarries at Amherst in Amherst Township, and along the gorge of the Black River just north of Elyria. The upper part of the formation at Elyria is of a deep red color, whereas the lower part is bluish, red, and gray. The Bedford shale has not been utilized for ceramic purposes in Lorain County.

The horizon of the Bedford shale in Cuyahoga County comes to the surface along the Rocky River and its branches in Olmsted and Middleburg townships; along the Cuyahoga River Valley in Brooklyn, Independence, Brecksville, Northfield, Bedford, and Newburg townships; and along the Chagrin River Valley in Willoughby, Mayfield, and Orange townships. This formation is composed of both blue and reddish-brown shale along Rocky River and the lower Cuyahoga Valley, but farther to the east sandstone layers become prominent in the lower part.

In Strongsville Township, Cuyahoga County, the Bedford formation is being utilized for the manufacture of hollow tile by the Berea Brick and Tile Company, located on the west side of East Branch about 2¾ miles south of Berea. This plant, built in 1925, was destroyed by fire in 1927, but was rebuilt and was producing about 8,000 tile per day in 1929. A description of the exposures at the plant is as follows:

	Ft.	In.
Glacial drift	4	6
Shale, somewhat softened by weathering	9	0
Shale, bluish gray, somewhat arenaceous	20	0

A sample of the shale was cut on July 31, 1929, and was submitted for chemical analysis and physical tests. The results are as stated below:

Sample No. 45

Tests of Bedford shale from pit of Berea Brick & Tile Co., Berea, Cuyahoga County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.17
Water, combined, H_2O+	4.50
Silica, SiO_2	61.70
Alumina, Al_2O_3	18.68
Titanic oxide, TiO_2	1.12
Phosphorus pentoxide, P_2O_5	0.08
Ferric oxide, Fe_2O_3	3.36
Ferrous oxide, FeO	1.68
Lime, CaO	0.48

Oxide ratio

K_2O	.155	Al_2O_3	1.00	SiO_2	3.303
Na_2O	.010			TiO_2	0.060
CaO	.026			P_2O_5	0.004
MgO	.074				
FeO	.306				
MnO	.001				
RO	.572				

[1] Geol. Survey Ohio, Vol. II, p. 188, 1874.

Chemical analysis, continued

Magnesia, MgO............	1.38
Sodium oxide, Na_2O.......	0.20
Potassium oxide, K_2O......	2.90
Manganese oxide, MnO.....	0.02
Sulphur trioxide, SO_3.......	0.22
Ferrous sulphide, FeS_2.....	1.69
Carbon dioxide, CO_2........	0.12
Carbon, organic, C........	0.68

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material is rather plastic but it is not sticky or gummy. A good column is extruded from the die.

Time of slaking: 13.70 minutes.

Water of plasticity: 19.68 per cent.

Dry shrinkage:

Volume: 10.48 per cent.

Linear: 3.38 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 284 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	24.61	10.85	3.5	12.13	2.03	2.70
04	11.76	16.22	5.1	5.46	2.15	2.41
02	9.61	18.69	5.9	4.37	2.23	2.46
1	6.57	21.77	6.8	2.89	2.31	2.47
3	2.65	25.43	7.8	1.15	2.39	2.43
5	7.28	4.71	1.5	3.82	1.91	1.93

Fired modulus of rupture:

Cone 04, 3,860 pounds per square inch.

Cone 3, 4,243 pounds per square inch.

Fired specific impact strength:

Cone 05, 1.38 centimeter kilograms per square centimeter.

Cone 3, 1.15 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 3, 11,640 pounds per square inch.

Best firing range: Cone 08 to cone 3.

Overfiring temperature: Cone 3.

Pyrometric cone equivalent: Cone 13.

Scumming: Scumming takes place throughout the entire firing range of this material. Five pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: This material does not withstand the temperature necessary for the development of a good salt glaze.

Utilization: This shale was being used for the production of hollow tile. It can be utilized also for face brick and common brick. On firing the material develops a good red color at about cone 02.

In Brooklyn Township, Cuyahoga County, the Bedford shales are utilized for ceramic purposes at the Pearl plant of the Cleveland Builders

Supply & Brick Company, located about 1½ miles southwest of Brooklyn. The manufactured products consist of radial block for chimney and sewer work and hollow building block. The shale utilized is of the reddish-brown variety with a thickness of a little more than 20 feet. A measurement near the west edge of the pit is as follows:

	Ft.	In.
Reddish-brown shale material mixed with some glacial pebbles	2	0
Reddish-brown shale, not disturbed	20	6
Reddish-brown shale with a few thin layers of blue shale, to bottom of pit	2	0

The shale was sampled on August 13, 1929, at the place where the above section was taken. The composition and physical tests of the sample are as follows:

Sample No. 46

Tests of Bedford shale from pit of Cleveland Builders Supply and Brick Co., Pearl Street plant, Cleveland, Cuyahoga County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.96
Water, combined, H_2O+	5.45
Silica, SiO_2	57.20
Alumina, Al_2O_3	13.06
Titanic oxide, TiO_2	1.20
Phosphorus pentoxide, P_2O_5	0.15
Ferric oxide, Fe_2O_3	14.08
Ferrous oxide, FeO	1.36
Lime, CaO	0.65
Magnesia, MgO	1.62
Sodium oxide, Na_2O	0.35
Potassium oxide, K_2O	2.60
Manganese oxide, MnO	0.04
Sulphur, S	0.04
Carbon dioxide, CO_2	0.25
Carbon, organic, C	0.18

Oxide ratio

K_2O	.199				
Na_2O	.027				
CaO	.050				
MgO	.124			SiO_2	4.380
FeO	1.074	Al_2O_3	1.00	TiO_2	0.092
MnO	.003			P_2O_5	0.011
RO	1.477				

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material is very plastic. A badly featheredged column is extruded from the die.

Time of slaking: 128.47 minutes.

Water of plasticity: 22.03 per cent.

Dry shrinkage:

Volume: 16.59 per cent.

Linear: 5.25 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 427 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
012	29.90	3.12+	1.0+	16.10	1.85	2.64
010	27.71	1.97	0.7	14.60	1.90	2.62
08	20.80	9.77	3.2	10.10	2.05	2.50
06	10.80	18.71	5.9	4.77	2.28	2.55
04	2.81	21.32	6.7	1.19	2.35	2.41

Fired modulus of rupture:
Cone 010, 2,291 pounds per square inch.
Cone 06, 4,611 pounds per square inch.

Fired specific impact strength:
Cone 09, 0.999 centimeter kilograms per square centimeter.
Cone 06, 1.46 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 06, 4,241 pounds per square inch.

Best firing range: Cone 010 to cone 04.

Overfiring temperature: Cone 02.

Pyrometric cone equivalent: Cone 14-15.

Scumming: Scumming takes place throughout the entire firing range of this material. One pound of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: This material does not withstand the temperature necessary for the development of a good salt glaze.

Utilization: This shale was being used for the production of radial block, fireproofing, and common brick. Another possible use is for drain tile. On firing the material develops a good red color at cone 04.

The horizon of the Bedford shale east of Cuyahoga County outcrops through southern Lake and parts of southern Ashtabula and northern Trumbull counties. Throughout these districts the surface is covered with a thick mantle of glacial drift and the bedrock is not exposed except along the major drainage lines. The Bedford formation in this area is a bluish-gray shale with some thin beds of sandstone. The thickness on an average is about 50 feet. This shale has not been utilized in Lake, Ashtabula, or Trumbull counties for the manufacture of brick or tile.

Analyses of Bedford shale[1]

	1	2
Silica, SiO_2	57.28	57.40
Alumina, Al_2O_3	21.13	21.20
Iron oxide, Fe_2O_3	8.52	6.57
Magnesia, MgO	2.13	1.40
Lime, CaO	5.79	1.00
Soda, Na_2O	....	1.00
Potash, K_2O	....	4.10
Combined water, H_2O	5.22	7.75
	100.07	100.42

No. 1—Bedford shale, northern Ohio. Chemist not given.
No. 2—Same shale, different sample and another chemist.

[1] Geol. Survey Ohio, Vol. VII, pp. 133-34, 1893.

Sunbury Shale

The Sunbury shale is a thin and persistent formation across Ohio, outcropping immediately above the Berea sandstone which separates it from the top of the Bedford shale previously described. This formation has a thickness which varies from about 15 to 40 feet. In its characteristic development, the Sunbury is a black to dark brown shale which is high in carbonaceous material and which resembles the black portion of the Ohio shale in all its lithologic characteristics. Due to its high carbon content the Sunbury shale is not well suited for the manufacture of ceramic products.

Cuyahoga Formation

The Cuyahoga formation includes a thick series of rocks of rather variable character which comprises more than half of the Mississippian group and which outcrops as a broad belt across the State from Scioto to Huron, Lorain, and Cuyahoga counties and thence eastward to the Pennsylvania line. This formation is well defined throughout Ohio, as the base is underlain by the black Sunbury shale and as the top is marked by a thin conglomerate, the Berne member of the Logan formation. The Cuyahoga embraces nearly all varieties of the clastic sediments such as shale, sandstone, and conglomerate. The deposits were evidently laid down in shallow waters close to shore where the distribution of the material was influenced by changing currents, for rapid transitions in the character of the sediments are noted in short horizontal distances. Thus much yellow sandstone characterizes the Cuyahoga formation in western Scioto, Pike, and Ross, and eastern Adams counties as well as central and western Hocking and Fairfield counties and eastern Licking County; while gray or bluish-gray sandy shale is the predominating type in western Licking County and in the region of the Scioto Valley from Chillicothe south to the Ohio River.[1]

In northern Ohio, the Cuyahoga formation is predominantly a bluish-gray shale, although some sandstone is present in it.

The Cuyahoga formation of Ohio is variable in thickness. Between Chillicothe and Waverly it measures about 300 feet;[2] in the Hocking Valley region its maximum thickness is about 625 feet;[3] while in eastern Licking County, Hyde reports about 588 feet.[4] In Wayne County the total thickness determined from surface outcrops and well records is in excess of 600 feet.[5] Near Cleveland the entire thickness of the Mississippian rocks above the Berea, all of which is probably Cuyahoga in

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[1] Hyde, J. E., Stratigraphy of Waverly Formations of Central and Southern Ohio, Jour. Geology, Vol. XXIII, pp. 655-682, 757-779, 1915.
[2] Idem., p. 758.
[3] Idem., p. 670.
[4] Idem., p. 667.
[5] Geol. Survey Ohio, Bull. 24, 4th Ser., pp. 49-50, 1921.

age, is 320 feet,[1] while along Brandywine Creek in southern Cuyahoga County this same interval is 236 feet.[2] Near Huntsburg in Huntsburg Township, Geauga County, the shales and sandstones above the Berea total about 235 feet,[3] and this measurement includes about 30 feet of Sunbury shale which is not included in the Cuyahoga formation of central and southern Ohio.

The rocks of the Cuyahoga formation have served as valuable sources of materials for various purposes. Sandstone of this formation was formerly quarried for building stone at Buena Vista in Scioto County. It is now being worked for that purpose at McDermott in the same county. This stone was likewise formerly utilized at various places along the Hocking Valley in Hocking County for molding sand, glass sand, and building stone. Sand for the manufacture of low grades of glass is now being produced by the crushing, screening, and washing of the Cuyahoga sandstone exposed at Black Hand in eastern Licking County.

The shales of the Cuyahoga formation are now utilized for the manufacture of ceramic products in Scioto, Licking, Richland, Wayne, and Cuyahoga counties.

In Scioto County the Cuyahoga shales were formerly used for the manufacture of paving brick by the Portsmouth Paving Brick Company, the Peebles Paving Brick Company, the Carlyle Paving Brick Company, and the Scioto Fire Brick Company, all of which were located along the Ohio River Valley at or near Portsmouth.[4] Three of these companies have ceased operations, for at the present time the only plant using Cuyahoga shale in this vicinity is the Peebles Paving Brick Company, which operates two plants at Portsmouth. The material used is the blue to bluish-gray sandy shale which forms the upper part of the Cuyahoga formation at this locality. The shale is of excellent quality for the manufacture of paving brick and the supply of available material is practically unlimited. A measurement of the exposures in the pit of the Peebles Paving Brick Company is as follows:[5]

	Ft.	In.
Logan formation		
Sandstone	55	0
Shales and sandstone	158	0
Cuyahoga formation		
Shale, bluish, siliceous	35	0
Sandstone, ferruginous	2	0
Shales, bluish, siliceous	90	0

A sample of Cuyahoga shale from this pit was secured by A. E. MacGee of the National Bureau of Standards.

[1] Prosser, C. S., Geol. Survey Ohio, Bull. 15, 4th Ser., p. 74, 1912.
[2] Idem., p. 143.
[3] Idem., p. 316.
[4] Stout, Wilber, Geol. Survey Ohio, 4th Ser., Bull. 20, p. 473, 1916.
[5] Idem., p. 471.

Sample 203

Tests of the Cuyahoga shale from the pit of the Peebles Paving Brick Company, Portsmouth, Scioto County. (Tests by National Bureau of Standards.)[1]

Chemical analysis

Loss on ignition	5.2
Silica, SiO_2	64.2
Alumina, Al_2O_3	15.7
Ferric oxide, Fe_2O_3	7.1
Lime, CaO	0.5
Magnesia, MgO	1.6
Titanic oxide, TiO_2	1.1
Sodium oxide, Na_2O	0.5
Potassium oxide, K_2O	3.0
Sulphur, S	0.0
Total carbon, C	0.3

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .19 \\ Na_2O & .03 \\ CaO & .03 \\ MgO & .10 \\ FeO & .41 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 4.09 \\ TiO_2 & 0.07 \end{array}\right.$$

RO .76

Physical tests

Tempering water:	About 20 per cent.
Drying linear shrinkage:	About 3 to 4 per cent.
Drying volume shrinkage:	About 12 to 13 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	0.3	0.8	12.8	Buff
Cone 06	3.0	8.7	11.3	Salmon
Cone 04	4.2	12.2	7.5	Reddish tan
Cone 03	6.9	19.4	3.8	Brick red
Cone 4	6.9	19.2	1.2	Dark red
Cone 6	9.6	26.1	1.2	Light maroon
Cone 7	8.3	22.9	1.1	Maroon
Cone 8	7.2	20.1	0.6	Maroon

Overburning temperature: Cone 9 (1,250°C. or 2,282°F.).
Best apparent burning range: Cone 04 to cone 6 (1,050°C. to 1,190°C. or 1,922°F. to 2,174°F.).
Total linear shrinkage at cone 6: About 13 to 14 per cent.
Deformation temperature: Cone 12 (1,310°C. or 2,390°F.).

From Portsmouth the outcrops of the Cuyahoga formation extend northward through Scioto, Pike, northwest part of Jackson, eastern Ross, northwest Vinton, eastern Pickaway, western Hocking, and Fairfield counties.

Throughout the eastern part of this belt of exposures north of Scioto County, the outcrops are composed of massive sandstone or thin-bedded sandstone interstratified with thin shale zones. In central Scioto, Pike, and Ross counties as far north as Chillicothe, there is little sandstone in this deposit and the shales are possible sources for the manufacture of

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

ceramic products. They are not utilized along the Scioto Valley above Portsmouth.

The surface rocks of Licking County are chiefly of Mississippian age with small areas of Pennsylvanian rocks, in large part outliers in the eastern one-third of the county. A conspicuous member of the Cuyahoga formation is a massive sandstone, 100 feet or so in thickness, which is known as the Black Hand sandstone and which forms conspicuous cliffs along the Licking River in Hanover Township. The Black Hand sandstone is the upper member of the Cuyahoga formation. West from Hanover Township this sandstone is believed to pass by gradations into sandy shale, although few exposures of this shale are found.

North of Licking County the Cuyahoga formation outcrops through western Knox, eastern Morrow, and over much of Richland, Ashland, and the western half of Wayne counties. Thick sandstones are present in this formation in eastern Knox County and in southeastern Richland and southern Ashland counties, while farther to the west the sandstones are less pronounced and sandy shales or shale interbedded with thin sandstone take their place.

Shales of the Cuyahoga formation have not been utilized for the manufacture of ceramic products in Holmes and Ashland counties.

In Richland County the Cuyahoga shales are being used for the manufacture of brick and tile in the southwestern corner of Weller Township. The companies operating are the Mansfield Shale Products Company, the North American Brick and Clay Products Company, and the Richland Shale Brick Company. A section of the shale at the eastern end of the pit of the Mansfield Shale Products Company, located in the northeast corner of Section 35, is as follows:

	Ft.	In.
Glacial drift	3	0
Shale, yellowish gray, slightly arenaceous, with a few iron carbonate concretions	5	6
Shale, grayish blue, slightly arenaceous, with a few thin layers of iron carbonate	14	6

The maximum thickness of the shale which has been worked at this plant is about 40 feet. The manufactured product is of fair quality, but the shale lacks the amount of sand necessary to yield the best results. This shale was sampled on August 3, 1929, at the place where the above section was secured. The results of the tests on this sample are as follows:

Sample No. 42

Tests of Cuyahoga shale from the pit of the Mansfield Shale Products Company, Weller Township, Richland County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	0.83
Water, combined, H_2O+..	5.72
Silica, SiO_2..............	59.34
Alumina, Al_2O_3............	19.45
Titanic oxide, TiO_2........	0.83
Phosphorus pentoxide, P_2O_5	0.21
Ferric oxide, Fe_2O_3........	2.43
Ferrous oxide, FeO.......	3.51
Lime, CaO................	0.62
Magnesia, MgO...........	1.60
Sodium oxide, Na_2O.......	0.27
Potassium oxide, K_2O.....	3.80
Manganese oxide, MnO....	0.03
Sulphur trioxide, SO_3......	0.05
Ferrous sulphide, FeS_2....	0.22
Carbon dioxide, CO_2.......	0.92
Carbon, organic, C........	0.41

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .195 \\ Na_2O & .014 \\ CaO & .032 \\ MgO & .082 \\ FeO & .300 \\ MnO & .001 \\ & \overline{} \\ RO & .624 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.051 \\ TiO_2 & 0.043 \\ P_2O_5 & 0.010 \end{array}\right.$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has good plasticity. A good column is extruded from the die.

Time of slaking: 49.76 minutes.

Water of plasticity: 20.94 per cent.

Dry shrinkage:

Volume: 13.61 per cent.

Linear: 4.35 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 347 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	26.21	16.32	5.2	9.93	2.64	3.57
04	11.51	20.82	6.5	5.14	2.35	2.66
02	7.52	22.39	7.0	3.30	2.33	2.53
1	5.06	24.34	7.5	2.15	2.36	2.48
3	4.11	26.66	8.2	1.70	2.41	2.50
5	1.50	25.02	7.7	0.63	2.40	2.44
7	1.50	21.76	6.8	0.63	2.26	2.31

Fired modulus of rupture:

Cone 05, 3,261 pounds per square inch.

Cone 3, 5,039 pounds per square inch.

Fired specific impact strength:
Cone 05, 1.34 centimeter kilograms per square centimeter.
Cone 3, 1.12 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 3, 10,234 pounds per square inch.
Best firing range: Cone 08 to cone 3.
Overfiring temperature: Cone 5.
Pyrometric cone equivalent: Cone 15.

Scumming: Scum occurs on all trials fired to cone 3 and lower but scum is not apparent on trials fired above cone 3. Two pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: A salt glaze is produced at 2,100°F. and at 2,050°F. The color of the glaze produced at 2,100°F. is a brownish-green on a pinkish-gray background while the glaze produced at 2,050°F. has a similar color but shades to a brown in places. The glaze produced at 2,100°F. has a deep chocolate brown color when $BaCO_3$ is added to the material.

Utilization: This shale was being utilized for the production of face brick and common brick. Because of its good working properties this material can probably be utilized for the production of hollow tile. A good red color is produced at cone 06.

The upper part of the Cuyahoga formation is exposed at many places throughout central, western, and northern Wayne County. Here the exposed portion consisting of sandstones and shales has a thickness of about 245 to 265 feet.[1] The general character of the formation is illustrated by the following geologic section of the exposure in Sections 3 and 10, Congress Township.[2]

	Ft.	In.
Black Hand member		
Gray-blue shales, with a few ironstone concretionary layers, exposed on slope west of private road	30	0
Armstrong member		
Massive gray to buff, fine-grained sandstone	17	0
Burbank member		
Sandstone with 5 to 10 per cent of shale (transition beds)	8	0
Covered	12	0
Shale, grayish blue, with about 20 per cent of fine-grained sandstone in beds ½ to 1 inch in thickness	15	0
Covered	1	0
Sandstone, fine-grained, grayish yellow	..	4
Shale with 25 per cent sandstone in 1 to 2 inch beds	6	0
Fine-grained sandstone with thin shale partings	1	3
Dark gray shale	1	6
Fine-grained, grayish-brown sandstone	..	8
Grayish-blue shale, with a few sandstone layers 1 to 2 inches thick	17	0
Fine-grained sandstone and shale, alternating in about equal amounts, in beds of ½ to 1½ in.	10	0
Grayish-blue shale with a small amount of sandstone	2	6
Grayish-brown, fine-grained sandstone with thin shale layers	2	2
Dark gray, gritty shale with thin sandstone beds	2	8
Fine-grained, gray sandstone	2	8

[1] Conrey, G. W., Geol. Survey Ohio, 4th Ser., Bull. 24, p. 49, 1921.
[2] Idem., pp. 52-53.

The top part of the Cuyahoga formation is being utilized for the manufacture of face brick and paving block by the Medal Brick and Tile Company at Wooster, Ohio. A section of the rock exposures in the pit is as follows:

	Ft.	In.
Logan formation		
8. Fine-grained buff sandstone, badly shattered	11	0
7. Fine-grained, gray to buff sandstone	6	0
6. Conglomerate, fine-grained, *Berne* member	..	10
Cuyahoga formation		
5. Bluish-gray sandy shale interbedded with thin sandstone	8	0
4. Bluish-gray micaceous and argillaceous sandstone, medium grained	4	0
3. Bluish-gray shale with a few thin layers of buff, fine-grained sandstone	8	0
2. Bluish-gray shale with a few thin zones of iron carbonate concretions	18	3
1. Bluish-gray shale, somewhat sandy, with many thin layers and small concretionary masses of iron carbonate	26	3

The bluish-gray shales of zone 1 were formerly used at this plant for paving block, but due to the harmful effects of the iron carbonate nodules present in this shale, the practice was discontinued and at the present zones 2, 3, 4, and the lower half of zone 5 of this section are utilized for that purpose. To meet the requirements for face brick, less sandy material is necessary in the mixture and, therefore, the shale of zones 2 and 3 only are utilized for paving block. A sample of the materials of zones 2, 3, 4, and the lower 4 feet of zone 5 was cut on August 2, 1929, and was submitted for chemical analysis and other tests with the following results:

Sample 43

Tests of Cuyahoga shale from pit of the Medal Brick and Tile Company, Wooster, Wayne County

Chemical analysis

Downs Schaaf, analyst

Water, hydroscopic, H_2O-	0.90
Water, combined, H_2O+	5.93
Silica, SiO_2	63.75
Alumina, Al_2O_3	13.91
Titanic oxide, TiO_2	1.22
Phosphorus pentoxide, P_2O_5	0.11
Ferric oxide, Fe_2O_3	4.61
Ferrous oxide, FeO	3.02
Lime, CaO	0.50
Magnesia, MgO	1.21
Sodium oxide, Na_2O	0.14
Potassium oxide, K_2O	3.30
Manganese oxide, MnO	0.06
Sulphur trioxide, SO_3	0.16
Carbon dioxide, CO_2	0.60
Carbon, organic, C	0.56

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .238 \\ Na_2O & .010 \\ CaO & .036 \\ MgO & .087 \\ FeO & .515 \\ MnO & .004 \\ & \overline{} \\ RO & .890 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 4.583 \\ TiO_2 & 0.087 \\ P_2O_5 & 0.008 \end{array}\right.$$

Physical properties, determined by Chester R. Austin
Properties in green state

Workability: This material is rather short. A featheredged column is extruded from the die.

Time of slaking: 18.23 minutes.

Water of plasticity: 18.90 per cent.

Dry shrinkage:

Volume: 9.29 per cent.

Linear: 3.01 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 221 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	24.18	10.18	3.3	11.94	2.02	2.67
04	18.50	15.04	4.8	8.66	2.14	2.63
02	16.70	17.74	5.6	6.75	2.22	2.59
1	11.80	20.20	6.3	5.17	2.29	2.58
3	9.23	22.45	7.0	3.92	2.35	2.59
5	5.17	23.10	7.2	2.18	2.37	2.36
8	5.19	20.83	6.5	2.26	2.30	2.42

Fired modulus of rupture:

Cone 04, 1,674 pounds per square inch.

Cone 5, 3,164 pounds per square inch.

Fired specific impact strength:

Cone 05, 1.43 centimeter kilograms per square centimeter.

Cone 4, 1.40 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 5, 11,389 pounds per square inch.

Best firing range: Cone 06 to cone 5.

Overfiring temperature: Cone 8.

Pyrometric cone equivalent: Cone 11-12.

Scumming: Scum is not apparent on trials fired to cone 3 and higher, but scum is present on trials fired below cone 3. Two pounds of $BaCO_3$ per ton of material is required to prevent scumming.

Salt glazing: A good dark brown colored salt glaze with some yellowish green mottling is produced at 2,050°F. The color of the glaze produced at 2,100°F. is a brownish-green on a pinkish-gray shading to a red. When $BaCO_3$ is added the glaze has a chocolate brown color.

Utilization: This shale was utilized for the production of paving brick, face brick, and common brick. The fired material has a stony structure. A good red color is developed at cone 02.

The Cuyahoga formation reaches its greatest width of outcrop through Richland, Ashland, and Wayne counties, from which it extends north and northeast through Huron, Lorain, and Medina into Cuyahoga County. In its outcrop areas in Huron, Medina, and Lorain counties the Cuyahoga formation consists of soft, bluish-gray shales and fine-textured, thin-bedded sandstones interbedded with shale. In these counties the Cuyahoga formation has not been utilized for the manufacture of ceramic products and tests of its quality for such purposes have not been made.

In Cuyahoga County the outcrops of the Cuyahoga formation, which here includes all the Mississippian series above the Sunbury shale, are limited for the most part to the eastern and southern portions. The formation has a thickness approaching 395 feet near South Brooklyn, Cleveland.[1] The thickness of the formation is expected to be irregular in the county as the upper surface of the formation is a plane of disconformity. The lower part consists of dark clay shales, while the upper portion is made up of bluish shales with thin-bedded sandstone. The following is a section of the Cuyahoga formation secured by C. S. Prosser along Willow Brook, some two miles east of Strongsville in Strongsville Township. For sake of brevity some of the details of the original section have been omitted here, but the character of the rock succession of the Cuyahoga is well shown.[2]

	Ft.	In.
Highest outcrops, mainly thin, shaly, blue sandstones, below which are blue shales, containing thin, sandstone layers and calcareous, concretionary ones	15	0
Mainly bluish, somewhat arenaceous shales, with numerous thin sandstone layers and calcareous, concretionary ones	10	0
Bluish shales, alternating with thin blue sandstones. The lower shales are rather arenaceous and contain calcareous nodules of blue color, which weather to a rusty brown	25	0
Mainly bluish, fine shales, with numerous calcareous concretions, some of which are fossiliferous	10	0
Blue, shaly sandstone zone	1±	
Bluish shales, with rather numerous layers of thin sandstones	19	0
Bluish-gray, shaly sandstone, which is slightly calcareous and contains some poorly preserved fossils	..	6±
Bluish-black shales with thin sandstone and concretionary layers	25	0
Bluish-black shales with thin sandstone and concretionary layers, which are calcareous	20	6
Blue and compact sandstone layer	..	6±
Bluish-black, soft shales, with an occasional thin, blue sandstone and calcareous, concretionary layer, which weathers to a rusty brown color	20	0
Sandstone layer with *Spirophyton*	14	0
Bluish-black shale which is somewhat gritty	10	4
Shaly, blue sandstone to arenaceous shale	3	0
Bluish sandstone zone, with trails on under surface	..	8
Mainly blackish, somewhat gritty shale containing nodular, rusty-colored, calcareous concretions	8	0
Thin, bluish, shaly sandstone which weathers to a rusty color, 3 to 4 inches thick	..	3
Soft, black, argillaceous shale	50	0

Neither the top nor the bottom of the Cuyahoga beds is shown in this

[1] Prosser, C. S., Geol. Survey Ohio, 4th Ser., Bull. 15, p. 33, 1912.
[2] Idem., pp. 490-491.

section although the thickness of the formation in Cuyahoga County will probably not exceed 400.

In Cuyahoga County the Cuyahoga formation forms the highlands in Euclid, Mayfield, Bedford, Independence, Parma, and Middleburg townships and is capped with small areas of Pennsylvanian rocks in Strongsville, Royalton, Brecksville, Solon, Orange, and Warrensville townships. The shale has been used extensively for the manufacture of face brick and fireproofing at the Valley View plant of the Cleveland Builders Supply and Brick Company located about one-half of a mile northwest of Willow in Newburg Township. This shale is likewise used for the manufacture of a similar product at the plant of the Independent Brick and Tile Company located about one-half mile south of the former plant. The shale worked at these two plants is dark blue to black in color, is of rather uniform appearance, and is somewhat siliceous, although sandstone layers are generally wanting. The stratigraphic position of these pit exposures with respect to the bottom of the Cuyahoga has not been definitely determined, but it is certain that they lie in the lower half of the formation.

The Cuyahoga formation outcrops in every township in Summit County with the exception of Green, Springfield, and Tallmadge. In general, the upper half of the formation consists of bluish colored shales and sandstones, which in some localities are massive, while the lower part is composed of soft black to bluish black shale. The general features of this formation in Summit County are illustrated by the following section measured by C. S. Prosser about one mile north of Everitt in Boston Township:[1]

	Ft.	In.
Blue argillaceous shale, with numerous thin to concretionary layers of compact blue limestone, ½ to 1 inch in thickness, which weathers to a rusty color on the surface and projects from the shale banks..	9	0
Two layers of compact limestone, about ¾ of an inch in thickness and separated by blue shale..............................	..	3
Blue shale	..	9
Blue shale, alternating with thin sandstone at the top of this zone. The sandstone of the middle portion is thicker than that of the upper and lower parts of the zone and is rather massive. The basal portion of the zone consists of thin, blue sandstones which weather to a buff color, some of the layers 6 inches thick, alternating with bluish shales. The zone is mainly a sandstone one...............	18	0
Arenaceous shale to thin sandstone............................	2	0
Blackish, soft, argillaceous shales to the base of the overlying arenaceous deposits	90	0
Small fall in run formed by a blue, rather fine-grained sandstone which on weathering tends to split up into thin layers.............	1	6
Blackish, soft, argillaceous shale..............................	3	6
Thin sandstone layer, 1 inch thick, blue and fine-grained............	..	1

[1] Geol. Survey Ohio, 4th Ser., Bull. 15, pp. 152-153, 1912.

Some of the details of the original description have been omitted, but the rock succession is well shown.

While the entire thickness of the Cuyahoga is not represented in this section, this formation has been penetrated by the drill at Kenmore and Barberton. At Kenmore the interval from the bottom of the Pennsylvanian rocks to the top of the Berea is 298 feet.[1] This interval includes the Cuyahoga formation and the underlying Sunbury shale, probably 15 feet or so in thickness, which was not differentiated. In the Barberton well the Cuyahoga formation, including the Sunbury shale, is about 310 feet.[2] A measurement of the outcrops along Brandywine Creek north of Akron gives a thickness of 221 feet for the Cuyahoga formation.[3] The shales of the Cuyahoga formation have not been utilized for the manufacture of ceramic products in Summit County.

In Geauga County the Cuyahoga formation outcrops as a fringe on the western, northern, and eastern borders. It extends into southern Lake County on the north and probably into western Ashtabula County on the east. The deeper river valleys in the central part of the county have been cut into the top of this formation. The lithological character of the series is similar to that of Cuyahoga County, with black to dark bluish-gray shales, predominating in the lower portion, and thin-bedded sandstone prominent in the upper part. Due to the cover of glacial drift and the somewhat subdued character of the topography, the total thickness of the formation is not easy to determine from surface exposures. Prosser, however, reports the interval from the base of the Sharon conglomerate to the top of the Berea sand to be about 127 feet as measured on the side of the Little Mountain located on the north boundary of Chardon Township.

The Cuyahoga formation outcrops over a belt of somewhat varying width in Trumbull County, including the southwestern, central, and northeastern parts. The outcrops extend to the southeast along the Mahoning River Valley across the northeastern part of Mahoning County to the State line and probably to the northeast over a small area in southeastern Ashtabula County. The general features of the formation in this county are similar to that in the bordering areas to the northwest. The following section is a measurement of exposures near Orangeville, Hartford Township:

	Ft.	In.
Shale, bluish-gray, arenaceous, which has weathered to a dirty brown color	13	0
Sandstone, bluish-gray, fine-grained	0	7
Shale, bluish-gray, somewhat sandy	4	10
Sandrock, bluish-gray, fine-grained	0	3
Shale, bluish-gray, more sandy than shale above	2	6

[1] Prosser, C. S., Geol. Survey Ohio, 4th Ser., Bull. 15, pp. 173-4, 1912.
[2] Idem. p. 177.
[3] Idem., p. 143.

The thickness of the beds at this exposure is about 21 feet. The beds apparently occur in the lower part of the Cuyahoga formation, for the base of this section is about 30 feet above the Berea sandstone which has been penetrated by well borings at Orangeville.[1]

A sample of the rock described in the above section was cut on August 16, 1929, for analysis and other tests. The results are as follows:

Sample No. 44

Tests of Cuyahoga shale near Orangeville, Trumbull County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	2.02
Water, combined, H_2O+..	5.02
Silica, SiO_2..............	60.22
Alumina, Al_2O_3............	19.60
Titanic oxide, TiO_2........	0.86
Phosphorus pentoxide, P_2O_5	0.18
Ferric oxide, Fe_2O_3........	4.49
Ferrous oxide, FeO.......	1.24
Lime, CaO...............	0.40
Magnesia, MgO...........	1.29
Sodium oxide, Na_2O.......	0.30
Potassium oxide, K_2O.....	3.40
Manganese oxide, MnO....	0.07
Sulphur, S................	0.10
Carbon dioxide, CO_2.......	0.33
Carbon, organic, C........	0.60

Oxide ratio

K_2O	.173			SiO_2	3.072
Na_2O	.015			TiO_2	0.044
CaO	.020	Al_2O_3	1.00	P_2O_5	0.009
MgO	.066				
FeO	.269				
MnO	.004				
RO	.547				

Physical properties, determined by Chester R. Austin
Properties in green state

Workability: This material is very plastic. A very good column is extruded from the die.

Time of slaking: 18.37 minutes.

Water of plasticity: 24.61 per cent.

Dry shrinkage:

Volume: 14.26 per cent.

Linear: 4.54 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 244 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	24.10	14.19	4.5	12.02	2.00	2.66
04	15.82	19.89	6.2	7.33	2.15	2.56
02	10.44	23.77	7.4	4.67	2.26	2.52
1	6.94	26.55	8.2	2.97	2.34	2.51
3	5.32	28.23	8.6	2.22	2.39	2.53
5	2.66	27.88	8.5	1.11	2.39	2.45
7	2.19	24.91	7.7	0.95	2.30	2.35
8	1.96	23.42	7.3	0.87	2.25	2.30

[1] Prosser, C. S., Geol. Survey Ohio, 4th Ser., Bull. 15, pp. 346-347, 1912.

Fired modulus of rupture:
Cone 04, 3,020 pounds per square inch.
Cone 3, 4,745 pounds per square inch.
Fired specific impact strength:
Cone 05, 1.38 centimeter kilograms per square centimeter.
Cone 3, 1.19 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 3, 14,137 pounds per square inch.
Best firing range: Cone 08 to cone 3.
Overfiring temperature: Cone 5.
Pyrometric cone equivalent: Cone 15.

Scumming: Scum occurs on all trials fired to cone 1 and lower but scum is not apparent on trials fired above cone 1. One pound of $BaCO_3$ per ton of material is required to prevent scumming.

Salt glazing: A good salt glaze having a reddish brown color with some brownish-green and pinkish-gray mottlings is produced at 2,100°F. The glaze produced at 2,050°F. has a somewhat more greenish-brown cast. When $BaCO_3$ is added the glaze has a chocolate brown color.

Utilization: This shale was not being utilized in 1929 for ceramic purposes. It can probably be used for the production of drain tile, hollow tile, face brick, and common brick. A good red color is developed at cone 02.

Logan Formation

The Logan formation, which forms the top of the Mississippian clastic series in Ohio, consists of sandstones, shaly sandstones, and sandy shales. According to Hyde this formation can be traced from the Ohio River in Scioto County to Wayne County with some change but without loss of essential characteristics.[1] Outcrops of the series are found in Scioto, Pike, Jackson, Ross, Vinton, Hocking, Fairfield, Perry, Licking, Muskingum, Knox, Coshocton, Holmes, Ashland, and Wayne counties. The thickness of the Logan is quite variable, due in part at least to post-Mississippian erosion, which at many places has removed part of this formation. If sediments of Logan time ever extended into northern Ohio they were entirely removed during this erosion period as the formation has not been recognized with certainty north of Wayne County.

Although the Logan is predominantly a sandstone formation, local shale phases occur where the material is well adapted to the production of brick. Shale from the Logan formation is now being utilized for the manufacture of brick by the Hanover Brick Company, Hanover, Licking County. A measurement of the rock exposures in the pit is as follows:

	Ft.	In.
Sandstone, buff, fine-grained	25	0
Shale, gray, very sandy	19	8
Shale, bluish-gray with some fine-grained sand	22	8
Bottom of pit.		

[1] Geol. Survey Ohio, 4th Ser., Bull. 31, p. 51, 1927.

A sample of shale from this pit was collected by A. E. MacGee of the National Bureau of Standards.

Sample No. 205

Tests of the Logan shale from the pit of the Hanover Brick Company, Hanover, Licking County. (Tests by the National Bureau of Standards.)[1]

Chemical analysis

Loss on ignition	5.3
Silica, SiO_2	59.7
Alumina, Al_2O_3	19.5
Ferric oxide, Fe_2O_3	6.7
Lime, CaO	0.4
Magnesia, MgO	1.5
Titanic oxide, TiO_2	1.1
Sodium oxide, Na_2O	0.3
Potassium oxide, K_2O	3.6
Sulphur, S	0.2
Total carbon, C	1.0

Oxide ratio

K_2O	.18	Al_2O_3	1.00	SiO_2	3.06
Na_2O	.01			TiO_2	0.05
CaO	.02				
MgO	.08				
FeO	.31				
RO	.60				

Physical tests

Tempering water:	About 23 per cent.
Drying linear shrinkage:	About 4 to 5 per cent.
Drying volume shrinkage:	About 15 to 16 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	1.0	2.9	15.0	Reddish buff
Cone 06	2.1	6.3	12.8	Salmon
Cone 04	5.5	15.6	6.7	Tan
Cone 03	5.6	15.8	6.7	Reddish brown
Cone 02	6.8	19.0	4.5	Reddish buff
Cone 01	7.9	22.0	2.5	Light red
Cone 1	9.4	25.7	2.6	Light red
Cone 3	8.5	23.4	1.3	Red
Cone 4	7.0	19.6	0.9	Maroon

Overburning temperature: Cone 5 (1,180°C. or 2,156°F.).

Best apparent burning range: Cone 04 to cone 1 (1,050°C. to 1,125°C. or 1,922°F. to 2,057°F.).

Total linear shrinkage at cone 1: About 14 per cent.

Deformation temperature: Cone 12 to cone 13 (1,310°C. to 1,350°C. or 2,390°F. to 2,462°F.).

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

PENNSYLVANIAN SYSTEM

The deposits laid down in Ohio during the Pennsylvanian period outcrop over an area of about 10,464 square miles in the southeast one-third of the State. This area forms an elongated belt of varying width extending from the Ohio River in Scioto, Lawrence, and Gallia counties on the south, to Geauga and Trumbull counties on the north. To the east it extends to the State line in Jefferson, Columbiana, Mahoning, and southern Trumbull counties. North and west of the Pennsylvanian outcrops in Ohio appears the bordering fringe of the older Mississippian exposures and to the southeast are the younger and overlying Permian beds. The northern and western borders of the Pennsylvanian are represented roughly by a line drawn from Sharon, Pennsylvania, through Niles, Chardon, Chagrin Falls, Akron, Medina, Orrville, Loudonville, Newark, Logan, and Sciotoville, whereas the southeastern margin is marked by a line passing through Dillonvale, Saint Clairsville, Barnesville, Macksburg, Renrock, Stockport, and Pomeroy The total average thickness of the Pennsylvanian in Ohio as measured on the outcrop is about 1,115 feet.

The Pennsylvanian rocks as a whole are of sedimentary origin, consisting in the order of their relative abundance of sandstone and shale, limestone, clay, coal, conglomerate, and iron ore. The conglomerate, which is closely associated with the sandstone in mode of origin and occurrence, is limited chiefly to the basal portion of the group and it comprises less than 1 per cent of the whole. The coals occur in 43 well-defined beds in the State and make up about 4.6 per cent of the total thickness; while the clays, which are usually found immediately below the coal, constitute about 7.4 per cent. The limestone beds are of both marine and brackish water origin. They constitute about 19 per cent of the total thickness of the group, but are better developed in the upper half of the system. The sandstones and shales, which intergrade with each other and which make up a large part of the intervals between the many coal beds, comprise about 68 per cent of the total thickness of the group. The Pennsylvanian rocks in Ohio are divided into four series which in ascending order are: Pottsville, Allegheny, Conemaugh, and Monongahela.

POTTSVILLE SERIES

The Pottsville which is the basal series of the Pennsylvanian group, is exposed in Ohio along the western margin of this coal-bearing group. The base upon which the Pottsville rests is an old erosion surface of much irregularity, and therefore the Pottsville is quite variable in thickness. Stout reports that variations occur ranging from 175 to 400 feet,[1] but the average in this State as a whole is about 255 feet. The extent of the outcrops of this series includes all or parts of the following counties:

[1] Geol. Survey Ohio, 4th Ser., Bull. 26, p. 104, 1923.

Trumbull, Mahoning, Columbiana, Geauga, Cuyahoga, Medina, Summit, Portage, Wayne, Stark, Holmes, Tuscarawas, Knox, Coshocton, Licking, Muskingum, Perry, Fairfield, Hocking, Vinton, Pike, Jackson, Gallia, Scioto, and Lawrence.

The rocks of the Pottsville series contain all the kinds common to the Pennsylvanian, but the proportions show much variation from the average. Taking this series as a whole, limestone is much less prominent than in the other series of the group, while the other elements increase in various proportions.

On an average the shale, sandstone, and conglomerate make up about three-fourths of the entire series. The iron ore beds are found chiefly in the Pottsville. The total average thickness of the coal is slightly above the mean for the entire group, but many of the individual beds are thin and are of only local economic importance. The top of the series is the base of the widely distributed Brookville or No. 4 coal. In the geologic section of the Pottsville series of Ohio the rock succession is described and the names of the chief coal, clay, limestone, shale, and sandstone beds are given with their average thickness. To simplify the section some of the less important members such as the iron ores, which are thin and irregular in their distribution, have been omitted.

Generalized Section of the Pottsville Series of Ohio.[1]

Series	Member	General description	Thickness Ft.	In.
Pottsville	Brookville No. 4	Clay, plastic	4	0
	Homewood	Shale and sandstone	10	0
	Tionesta No. 3b	Coal, local	1	0
		Clay, plastic	5	0
	Tionesta	Shale and sandstone	24	4
	Upper Mercer	Limestone and flint	1	8
	Bedford	Coal, patchy	1	0
		Clay, siliceous	3	0
	Upper Mercer	Shale and sandstone	11	0
	Upper Mercer No. 3a	Coal, local	1	0
		Clay, siliceous, plastic	3	0
	Middle Mercer	Shale and sandstone	13	0
	Lower Mercer	Limestone, steady, marine	2	0
	Middle Mercer	Coal, steady, thin	..	6
		Clay, siliceous, plastic	3	6
	Flint Ridge	Shale and sandstone	5	0
	Flint Ridge	Coal, thin; local	..	6
		Clay, plastic and flint	4	0
	Lower Mercer	Shale and sandstone	6	6
	Lower Mercer No. 3	Coal, steady, thin	1	0
		Clay, siliceous	3	0
	Vandusen	Shale and sandstone	23	0
	Lowellville or Poverty Run	Limestone or ore	1	0

[1] See Generalized Section, Geol. Survey Ohio, 4th Ser., Bull. 34, opposite p. 6, 1929.

Series	Member	General description	Thickness Ft.	In.
Pottsville	Vandusen	Coal, thin, unsteady	1	0
		Clay, impure	2	0
	Bear Run	Shale and sandstone	17	0
	Bear Run	Coal, local	1	6
		Clay, siliceous	3	0
	Massillon	Shale and sandstone	24	0
	Quakertown No. 2	Coal, patchy	2	0
		Clay, siliceous	5	0
	Anthony	Shale	22	3
	Anthony	Coal, thin	..	3
	Sciotoville	Clay, flint and plastic	4	0
	Sharon	Shale and sandstone	25	0
	Sharon No. 1	Coal, patchy	3	0
		Clay, impure	2	0
	Sharon	Conglomerate, patchy, and shale	15	0
	Harrison	Ore, local, impure, marine	1	0

The limestones of the Pottsville are all of marine origin and their position is either directly above coal beds or separated from the latter by a few inches of shale. The iron ores, which have been omitted in the general section of the Pottsville, usually occur close above the limestones but where the limestone is wanting, they are found embedded in the shales between the coal and the next clay higher in the series. In publications on the stratigraphy of the Pennsylvanian group it has not been the general practice, except in a few cases, to apply names to shale beds. Prominent sandstones appearing in the sections, however, have been named and such names have been used consistently in geologic literature. In this report the name of the first prominent underlying coal bed is used for the shales, except where such shales occur on the same stratigraphic horizon as a well-known sandstone formation. In the latter case the term used for the sandstone is applied to the corresponding shale facies. Names applied to shale beds are used for convenience in description.

Sharon Shale

In this report the term Sharon is used to include the rock strata in the interval between the top of the Sharon No. 1 coal and the bottom of the Sciotoville clay. Rocks on this horizon in Ohio consist of sandstones and shales, both of which are rather patchy in distribution. Early stages in the deposition of the Pottsville sediments consisted in the filling up of depressions on the old land surface existing at the beginning of Pottsville time. The distribution of lower Pottsville rocks, therefore, including the Sharon shales and even beds as high in the series as the Quakertown coal, depends upon the extent of such depressions. In Ohio the surface upon which the lower Pottsville rocks were deposited was very rough, at one locality the Sharon No. 1 coal appearing with the normal sequence above it, and at the next exposure a short distance away, the Sciotoville clay may rest in contact with the Mississippian strata with the Sharon shales entirely wanting. On an average the interval between the Sharon coal and Sciotoville clay, which is the horizon of the Sharon shale, is about 25 feet. The horizon of the Sharon shale is known chiefly from its outcrops in central and southern Ohio.

At places in the outcrop areas of the Sharon shale in southern Ohio there is a thin bed of iron ore, known as the Sharon ore, which either lies immediately on the Sharon coal or is embedded in the Sharon shale a few feet above the coal.

In Scioto County the Sharon horizon is exposed in Green, Porter, Harrison, Madison, and Jefferson townships. The member consists of both sandstone and shale with a thickness ranging from 3 to 40 feet. Exposures of Sharon shale on the Samuel Shoemaker farm in Section 26, Madison Township, have the measurements given in the following record.[1]

		Ft.	In.
Clay, flint, *Sciotoville*		3	0
Shales and covered	*Sharon*	24	0
Shales	*Sharon*	10	0
Shales and covered	*Sharon*	9	0
Coal, *Sharon*		..	4

In Pike County exposures of the Sharon horizon are present near the hilltops in Marion, Union, Beaver, and Jackson townships. In a portion of this area, notably in Jackson Township, sandstone is prominently developed on the Sharon horizon and in places it is conglomeratic. The Sharon horizon in Jackson County consists of both sandstone and shale. In general the shale bed lies immediately above the Sharon coal with a thickness ranging from 0 to 35 or 40 feet. Above the shale in most localities is a sandstone which is usually massive and at many places is conglomeratic in its lower part. The shale is of a gray to bluish-gray color and is generally siliceous or sandy in character. Outcrops of the Sharon shale horizon in Jackson County are found in Hamilton, Scioto, Liberty, Jackson, and Washington townships. The stratigraphic relations of the Sharon shale are well shown at an exposure on the Sawyer property in Section 7, Scioto Township. The record is as follows:[2]

		Ft.	In.
Clay, plastic, upper part siliceous, lower part "pink eye", *Sciotoville*		13	8
Sandstone, massive	*Sharon*	11	0
Shale	*Sharon*	13	6
Coal, *Sharon*		2	6

In some localities in Jackson County sandstone makes up a large part of the interval between the Sharon coal and the Sciotoville clay as shown

[1] Geol. Survey Ohio, 4th Ser., Bull. 20, pp. 490-491, 1916.
[2] Idem., p. 46.

in the following measurements secured by Wilber Stout in Section 2, Liberty Township:[1]

		Ft.	In.
Clay, flinty, siliceous	*Sciotoville*	1	6
Clay, light, soft	*Sciotoville*	10	6
Sandstone and covered, *Sharon*		23	0
Shale with thin ferruginous sandstone	*Sharon*	5	0
Sandstone, shaly	*Sharon*	5	0
Shale, blue	*Sharon*	7	0
Coal, shaly, *Sharon*		..	4
Clay, blue		2	6

The Sharon shale has not been utilized in Jackson County for the manufacture of ceramic products, although in some localities the character and thickness of the bed make it suitable for this purpose.

In Vinton County the Sharon shale is poorly developed as the lower Pottsville strata are wanting over large areas and as the Sciotoville clay either lies on the Mississippian strata or is separated from it by a few feet of sandstone or very sandy shale. Much the same condition is thought to exist throughout Perry and Hocking counties. At the State Brick Plant located in Section 5, Jackson Township, Perry County, about 2 miles northwest of Junction City, a bed of shale lying below the Sciotoville clay was formerly utilized in a small way for the manufacture of paving block. In Muskingum County the lower Pottsville rocks are best developed in Jackson and Licking townships. In this area the interval between the Sharon No. 1 coal and the Sciotoville clay varies from 10 to 30 feet. Gray to dark shales containing some nodules of iron ore characterize this interval. The following record measured by Wilber Stout in Section 7, Jackson Township, is typical for the county:

		Ft.	In.
Coal, bony, *Anthony*		..	6
Clay, dark	*Sciotoville*	1	0
Clay, light, siliceous	*Sciotoville*	9	6
Shale, gray	*Sharon*	10	0
Covered interval	*Sharon*	8	0
Shale, dark	*Sharon*	13	0
Shales, dark, with ore nodules, *Sharon* coal horizon		3	0

North of Muskingum County the horizon of the Sharon shale is above drainage along the major streams in the western half of Coshocton County and in all but the eastern third of Holmes County. In Wayne County the Sciotoville clay, which is the upper limit of the Sharon shale member, is wanting except in the southeastern part where it is underlain by sandrock. In eastern Wayne County sandstone is generally present above the Sharon coal.

The horizon of Sharon shale is due in Medina, Summit, Geauga,

[1] Idem., p. 55.

Portage, Trumbull, and Mahoning counties, but the region is heavily covered with drift and the horizon is not well known.

Anthony Shale

The shale which occupies the interval extending upward from the Anthony coal to the base of the Quakertown clay is considered in this report as the Anthony. Shale is the chief type of rock occupying this interval but over small local areas in Vinton, Jackson, and Scioto counties clay and coal are found lying close above the Anthony coal which are known as the Huckleberry clay and coal. Also at places in the outcrop areas in southern Ohio, an iron ore is found embedded in the shale above the Anthony coal which is only a few inches in thickness and which is known as the Guinea Fowl ore. Due to the uneven erosion surface upon which the Pennsylvanian group rests and due to the fact that deposition of sediments in the early stages of this period was limited to the basin and depressions on this erosion surface, the Anthony shale horizon is rather limited in extent. On the whole it is more extensive than the underlying Pottsville, but is less continuous than the Pottsville strata above the Quakertown No. 2 coal. The Anthony shale horizon is generally present on the outcrop through Scioto, Jackson, Vinton, Hocking, Perry, Licking, and Muskingum counties, although there are small local areas where the top of the Mississippian rocks rises above the horizon of this shale. Through Coshocton, Knox, and Holmes counties the Anthony shale horizon is generally wanting, but it appears again in parts of Wayne, Summit, Trumbull, and Mahoning counties. The average thickness of the Anthony shale in Ohio is about 22 feet.

The Anthony member in Scioto County outcrops in Green, Porter, Bloom, and Morgan townships, where the horizon is generally characterized by dark, siliceous shales. At a few localities, as at Gephart and Scioto Furnace in southwestern Bloom Township and near Sciotoville in Porter Township, the Huckleberry coal and clay appear in the section close above the Anthony coal. The Anthony shale has been utilized to some extent for the production of fire brick at the plant of Carlyle-Labold Company located in the east-central part of Section 12, Porter Township. The character and thickness of this shale are shown in the following section secured by Wilber Stout in 1924.

	Ft.	In.
Coal, *Quakertown*	1	1
Clay, plastic	3	11
Shale, gray, argillaceous	8	3
Shale, dark blue, siliceous	8	4
Shale, very siliceous	7	2
Shale, blue, argillaceous	8	2
Coal, *Huckleberry*	..	½

	Ft.	In.
Clay, plastic	9	0
Shale, dark, siliceous	14	0
Coal, *Anthony*	..	1
Clay, *Sciotoville*	5	0

A. E. MacGee, of the National Bureau of Standards, sampled the shale lying between the Huckleberry coal and the Quakertown clay, in October, 1926.

Sample No. 204

Tests of Anthony shale from pit of the Carlyle-Labold Company, Portsmouth, Scioto County. (Tests by Bureau of Standards.)[1]

Chemical analysis

Loss on ignition	8.3
Silica, SiO_2	60.5
Alumina, Al_2O_3	20.1
Ferric oxide, Fe_2O_3	5.9
Lime, CaO	0.2
Magnesia, MgO	1.0
Titanic oxide, TiO_2	1.1
Sodium oxide, Na_2O	0.0
Potassium oxide, K_2O	1.5
Sulphur, S	0.1
Total carbon, C	0.9

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .07 \\ Na_2O & .00 \\ CaO & .01 \\ MgO & .05 \\ FeO & .26 \\ & \overline{} \\ RO & .39 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.01 \\ TiO_2 & 0.05 \end{array}\right.$$

Physical tests

Tempering water:	About 25 per cent.
Drying linear shrinkage:	About 5 to 6 per cent.
Drying volume shrinkage:	About 18 to 19 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	1.7	5.1	16.5	Buff
Cone 06	2.2	6.4	14.5	Reddish buff
Cone 04	3.8	10.9	11.1	Tan
Cone 03	5.6	15.8	8.3	Reddish brown
Cone 6	6.7	18.8	5.0	Reddish gray
Cone 7	7.4	20.6	4.1	Reddish gray
Cone 8	8.9	24.5	2.8	Reddish gray
Cone 9	4.6	13.1	1.9	Mottled gun-metal

Overburning temperature: Cone 8 to cone 9 (1,225°C. to 1,250°C. or 2,237°F. to 2,282°F.).

Best apparent burning range: Cone 04 to cone 7 (1,050°C. to 1,210°C. or 1,922°F. to 2,210°F.).

Total linear shrinkage at cone 8: About 14 to 15 per cent.

Deformation temperature: Cone 14 (1,390°C. or 2,534°F.).

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

In Jackson County black shale and sandstone occur in the interval between the Anthony and Quakertown coals and in some localities the sandstone has replaced the upper coal bed. The thickness of this shale and sandstone series varies from 30 to 50 feet with an average of about 40 feet. Exposures of the Anthony shale horizon are found in Hamilton, Scioto, Liberty, Coal, Lick, and Jackson townships. The following measurements from Section 6, Coal Township, are typical.[1]

		Ft.	In.
Coal, *Quakertown*		2	6
Covered	*Anthony*	26	0
Shales, gray	*Anthony*	9	0
Coal blossom, *Anthony*		..	6

In Vinton County the horizon of the Anthony shale outcrops in Harrison, Richland, Eagle, Jackson, and Swan townships. Much the same conditions prevail as to the character of the beds on this horizon as are found in Jackson County, much sandstone being present which in some localities is of sufficient thickness to entirely replace the Quakertown coal horizon. When the Quakertown coal is present in Vinton County, its position is 25 to 40 feet above the Anthony coal. Similar relations are thought to exist in Hocking and Perry counties. In Section 5, Jackson Township, Perry County, the shales above the Sciotoville clay are now being utilized at the State Brick Plant for the production of paving block. A measurement of the exposures in the pit is as follows:

	Ft.	In.
Shales, sandy, estimated thickness	12	0
Sandstone	12	0
Shale, bluish-gray, somewhat sandy	8	6
Shale, dark	3	6
Shale, gray	1	0
Shale, bony	..	7
Shale, dark	2	6
Clay, gray, *Sciotoville*	4	0

The shale utilized at the plant has a thickness of about 16 feet and includes the beds between the top of the Sciotoville clay and the base of the 12-foot ledge of sandstone shown in the above record. This sandstone, with the sandy shales overlying it, is removed by stripping. A sample of the shale used at this plant was cut on September 25, 1929, and submitted for chemical analysis and physical tests.

[1] Stout, Wilber, Geol. Survey Ohio, 4th Ser., Bull. 20, p. 83, 1916.

Sample No. 21

Tests of Anthony shale from pit of the State Brick Plant, Junction City, Perry County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.52
Water, combined, H_2O+..	6.88
Silica, SiO_2..............	58.14
Alumina, Al_2O_3...........	17.68
Titanic oxide, TiO_2........	1.10
Phosphorus pentoxide, P_2O_5	0.15
Ferric oxide, Fe_2O_3........	6.23
Ferrous oxide, FeO.......	2.70
Lime, CaO................	0.38
Magnesia, MgO...........	0.80
Sodium oxide, Na_2O.......	0.10
Potassium oxide, K_2O.....	2.88
Manganese oxide, MnO....	0.08
Sulphur, S................	0.07
Carbon dioxide, CO_2.......	0.40
Carbon, organic...........	1.09

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .163 \\ Na_2O & .006 \\ CaO & .021 \\ MgO & .045 \\ FeO & .470 \\ MnO & .004 \\ \hline RO & .709 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SO_2 & 3.289 \\ TiO_2 & 0.062 \\ P_2O_5 & 0.008 \end{array}\right.$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: The column extruded from the die is slightly featheredged.
Time of slaking: 13.52 minutes.
Water of plasticity: 19.58 per cent.
Dry shrinkage:
Volume: 10.58 per cent.
Linear: 3.41 per cent.
Drying behavior: This material dries satisfactorily with ordinary care.
Dry modulus of rupture: 266 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	30.50	10.95	3.5	15.95	1.91	2.74
04	22.80	15.69	5.0	11.15	2.21	2.70
02	18.15	20.45	6.4	8.49	2.20	2.66
1	14.82	24.89	7.7	6.62	2.24	2.65
3	12.79	29.01	8.9	5.55	2.31	2.66
5	7.67	36.65	11.0	0.33	2.34	2.54
8	5.22	17.69	5.6	2.21	2.37	2.50

Fired modulus of rupture:
Cone 02, 2,457 pounds per square inch.
Cone 4, 3,137 pounds per square inch.
Fired specific impact strength:
Cone 03, 1.49 centimeter kilograms per square centimeter.
Cone 4, 1.37 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 4, 11,950 pounds per square inch.
Best firing range: Cone 06 to cone 4.
Overfiring temperature: Cone 7.
Pyrometric cone equivalent: Cone 13-14.
Scumming: A scum occurs on all trials fired to cone 1 and lower but scum is not apparent on trials fired above cone 1. Two pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The salt glaze developed at 2,100°F. is a yellowish-green and reddish-brown mottle. The glaze produced at 2,050°F. has some orange mottling. No glaze is produced at 2,100°F. when $BaCO_3$ is added.

Utilization: This shale was being used for the production of paving brick, face brick, and common brick. On firing the material develops a good red color at cone 01.

The Anthony shale horizon is above drainage in eastern Licking and western Muskingum counties. In Muskingum County the outcrops are limited to Newton, Hopewell, Licking, Falls, Jackson, and Cass townships, but the horizon is probably best developed in Licking and Jackson townships where the Anthony is made up of shales and shaly sandstone. The following section illustrates the stratigraphic succession in the southwestern part of Licking Township:[1]

		Ft.	In.
Shale and covered		10	0
Shale, black, *Quakertown* coal horizon		5	0
Clay, siliceous		1	0
Shale and shaly sandstone, *Anthony*		5	0
Clay, upper part dark, *Sciotoville*		3	0
Shale with scattered ore nodules	*Sharon*	7	0
Shale, gray	*Sharon*	10	0
Shale, black, *Sharon* coal horizon		1	0

In northeastern Ohio, including parts of Wayne, Stark, Medina, Summit, Portage, Trumbull, and Mahoning counties, where the horizon of the Anthony shale is due above drainage, the glacial drift is of such thickness and extent that few exposures occur and the detailed character of this member is not well known. In Baughman Township in eastern Wayne County, Conrey reports that the Quakertown coal and clay are underlain by shale, below which is gray to white sandstone.[2] In Medina County, shales lying a few feet above the Sharon conglomerate are now being utilized for the production of face brick at the plant of the Wadsworth Brick and Tile Co., one mile southwest of Wadsworth. The character and thickness of the shale exposures in the pit and vicinity are as follows:

	Ft.	In.
Glacial drift	2	6
Shale, yellowish, somewhat sandy	13	6
Shale, bluish gray, sandy	10	6
Bottom of pit	..	..
Sandstone, shale and covered	17	0
Pebble rock, *Sharon*, conglomerate	4	0

[1] Geol. Survey Ohio, 4th Ser., Bull. 21, p. 55, 1918.
[2] Geol. Survey Ohio, 4th Ser., Bull. 24, p. 99, 1921.

As the Sciotoville clay and Quakertown coal are not present in this vicinity, the exact correlation of these shales cannot be definitely determined. The bottom of the pit is about 17 feet above the top of the Sharon conglomerate. Both the shale and drift are utilized in the plant, which has a capacity of about 100,000 brick a day. On July 31, 1929, the shale in the pit, having a total thickness of about 24 feet, was sampled for chemical analysis and physical tests. The results are given below:

Sample No. 23

Tests of Anthony shale from pit of the Wadsworth Brick & Tile Company, Wadsworth, Medina County

Chemical analysis

Water, hydroscopic, H_2O-	0.62
Water, combined, H_2O+..	...
Silica, SiO_2..............	75.24
Alumina, Al_2O_3...........	10.96
Titanic oxide, TiO_2........	0.90
Phosphorus pentoxide, P_2O_5	0.15
Ferric oxide, Fe_2O_3........	4.01
Ferrous oxide, FeO.......	...
Lime, CaO................	0.40
Magnesia, MgO...........	0.61
Sodium oxide, Na_2O.......	0.51
Potassium oxide, K_2O.....	2.63
Manganese oxide, MnO....	trace
Sulphur trioxide, SO_3......	...

Analysis by U. S. Bureau of Mines

Oxide ratio

K_2O	.240				
Na_2O	.047			SiO_2	6.865
CaO	.036	Al_2O_3	1.00	TiO_2	0.081
MgO	.056			P_2O_5	0.014
FeO	.329				
MnO	...				
RO	.708				

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This shale has rather short plasticity. A fair column is extruded from the die.

Time of slaking: 26.60 minutes.

Water of plasticity: 16.26 per cent.

Dry shrinkage:

Volume: 8.54 per cent.

Linear: 2.77 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 239 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	28.20	2.02	0.7	15.06	1.87	2.60
04	26.56	1.85	0.6	13.85	1.91	2.60
02	25.90	3.78	1.3	13.20	1.92	2.60
1	25.18	5.65	1.9	12.65	1.96	2.62
3	24.40	7.47	2.4	12.22	2.00	2.64
5	19.92	9.02	2.9	9.78	2.04	2.53
7	16.00	13.20	4.2	7.61	2.10	2.49

Fired modulus of rupture:
Cone 1, 1,291 pounds per square inch.
Cone 7, 2,014 pounds per square inch.

Fired specific impact strength:
Cone 2, 1.38 centimeter kilograms per square centimeter.
Cone 7, 1.28 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 7, 11,690 pounds per square inch.

Best firing range: Cone 06 to cone 7.

Overfiring temperature: Not determined.

Pyrometric cone equivalent: Cone 13.

Scumming: Scum occurs on all trials fired to cone 2 and lower but scum is not apparent on trials fired above cone 2. Four pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: A good salt glaze is produced at 2,100°F. and at 2,050°F. The color is a good gray with a few yellowish green spots. When $BaCO_3$ is added the glaze produced at 2,100°F. has a grayish brown color.

Utilization: This shale was being used for the production of face brick and common brick. The fired material has a stony structure. A good red color is developed at cone 02.

In Summit County the lower Pottsville rocks are above drainage in the southern and eastern part, but due to the thick deposits of glacial drift few exposures occur. At Akron, Barberton, and Mogadore, lower Pottsville shales are used extensively for the production of sewer pipe and building tile with good results. Camp Bros. at Mogadore use the shales which lie above and below the Quakertown No. 2 coal, but the greater supply is from the bed above the coal and is therefore Massillon in age. Shale of good quality lying below the Quakertown coal horizon has been the chief source of material used for a number of years for the manufacture of sewer pipe at plant No. 25, of the American Vitrified Products Co. at Barberton. Some shale above this coal horizon is also utilized, as shown in the record of exposures in the pit located on the west bank of the Tuscarawas River about one mile south of town.

		Ft.	In.
Sandstone, coarse grained, yellowish	*Massillon*	16	0
Shale, bluish gray, a little sandy	*Massillon*	8	0
Shale, black, bony, *Quakertown* coal horizon		2	0
Clay, gray, sandy		3	0
Shale, bluish gray, somewhat sandy	*Anthony*	8	3
Shale, hard, bluish gray, sandy	*Anthony*	18	0

The coarse-grained sandstone appearing at the top of this section is not used as it would render the mixture too siliceous for the best results. All other beds in this section are utilized in the proportion delivered by the shovel. As determined in drilling for water supplies in the pit, the base of the shale exposure lies about 60 feet above the top of the Sharon conglomerate. The shale and clay described in this section were sampled on August 1, 1929. The sample was submitted for tests with the following results:

Sample No. 12

Tests of Anthony and Massillon shales from pit of Plant No. 25, American Vitrified Products Company, Barberton, Summit County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	0.90
Water, combined, H_2O+	5.01
Silica, SiO_2	61.47
Alumina, Al_2O_3	16.80
Titanic oxide, TiO_2	1.01
Phosphorus pentoxide, P_2O_5	0.18
Ferric oxide, Fe_2O_3	2.60
Ferrous oxide, FeO	4.33
Lime, CaO	0.44
Magnesia, MgO	0.74
Sodium oxide, Na_2O	0.32
Potassium oxide, K_2O	2.21
Manganese oxide, MnO	0.12
Sulphur trioxide, SO_3	trace
Ferrous sulphide, FeS_2	0.25
Carbon dioxide, CO_2	2.25
Carbon, organic, C	1.37

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .131 \\ Na_2O & .019 \\ CaO & .026 \\ MgO & .044 \\ FeO & .406 \\ MnO & .007 \\ \hline RO & .633 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.659 \\ TiO_2 & 0.060 \\ P_2O_5 & 0.010 \end{array}\right.$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has rather short plasticity. A featheredged column is extruded from the die.

Time of slaking: 22.33 minutes.

Water of plasticity: 18.23 per cent.

Dry shrinkage:

Volume: 13.70 per cent.

Linear: 4.38 per cent.

Drying behavior: This material dried satisfactorily with ordinary care.

Dry modulus of rupture: 290 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	24.91	9.90	3.2	12.38	2.00	2.66
04	20.34	11.71	3.8	9.95	2.05	2.58
02	17.98	14.11	4.5	8.55	2.11	2.56
1	16.17	16.89	5.3	7.29	2.18	2.59
3	14.30	18.71	5.9	6.42	2.23	2.60
5	11.80	19.20	6.0	5.23	2.25	2.55
7	9.35	20.65	6.4	4.11	2.27	2.50

Fired modulus of rupture:
Cone 1, 3,151 pounds per square inch.
Cone 7, 2,733 pounds per square inch.
Fired specific impact strength:
Cone 2, 1.29 centimeter kilograms per square centimeter.
Cone 7, 1.70 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 7, 8,451 pounds per square inch.
Best firing range: Cone 06 to cone 7.
Overfiring temperature: Cone 9.
Pyrometric cone equivalent: Cone 14-15.

Scumming: Scum occurs on trials fired to cone 2 and lower, but trials fired above cone 2 do not scum. Three pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: A good salt glaze is produced on this material at 2,050°F., the color being a very dark brown or gray with some yellowish-green-brown mottling. The glaze produced at 2,100°F. has much the same color. When $BaCO_3$ is added the glaze has a brown color with some white spots in the body showing through.

Utilization: This shale was being used for the production of sewer pipe. The fired material has a stony structure and develops a good red color at cone 02.

The lower Pottsville shales are due to outcrop over large areas in central and southern Portage County, but the region is so drift covered that little is known about the thickness and character of the beds. At Diamond, located in the east central part of Palmyra Township, shale above the Sciotoville clay is the source of raw materials used for the manufacture of ceramic products at plant No. 3 of the Universal Sewer Pipe Co., formerly owned by the United Clay Products Co. Both drain tile and building block of fair quality are produced at this plant. A section of the exposures in the pit is as follows:

		Ft.	In.
Glacial till		6	0
Fine silt and gravel		1	0
Glacial till, brown in color		2	0
Shale, yellowish brown, weathered, a little sandy	*Anthony*	1	0
Concretionary layer, ferrous carbonate	*Anthony*	..	6
Shale, yellowish-brown	*Anthony*	2	0
Shale, dark, somewhat carbonaceous	*Anthony*	4	0
Smut streak, *Anthony* coal horizon		..	1
Clay, mottled, *Sciotoville*		3	0

The materials used in the plant include clay, shale, and glacial drift in the proportions as it comes from the shovel. A sample from this pit consisting of the Anthony shale and Sciotoville clay was secured on August 12, 1929, and submitted for chemical analysis and burning tests. The results follow:

Sample No. 22

Tests of Anthony shale and Sciotoville clay from pit of Plant No. 3, Universal Sewer Pipe Company, Palmyra, Portage County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.10
Water, combined, H_2O+...	6.78
Silica, SiO_2	58.60
Alumina, Al_2O_3	21.88
Titanic oxide, TiO_2	1.25
Phosphorus pentoxide, P_2O_5	0.12
Ferric oxide, Fe_2O_3	4.29
Ferrous oxide, FeO	0.74
Lime, CaO	0.25
Magnesia, MgO	1.03
Sodium oxide, Na_2O	0.12
Potassium oxide, K_2O	2.41
Manganese oxide, MnO	0.01
Sulphur trioxide, SO_3	0.33
Ferrous sulphide, FeS_2	trace
Carbon dioxide, CO_2	0.30
Carbon, organic, C	0.93

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .110 \\ Na_2O & .005 \\ CaO & .012 \\ MgO & .047 \\ FeO & .210 \\ MnO & \ldots \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 2.678 \\ TiO_2 & 0.057 \\ P_2O_5 & 0.005 \end{array}\right.$$

$$RO \quad .384$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This shale has good plasticity. A good column is extruded from the die.

Time of slaking: 26.45 minutes.

Water of plasticity: 20.90 per cent.

Dry shrinkage:

Volume: 11.74 per cent.

Linear: 3.77 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 314 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	30.10	10.94	3.6	15.73	1.92	2.74
04	23.71	13.27	4.2	11.87	2.00	2.63
02	20.78	17.16	5.4	10.02	2.10	2.64
1	18.07	19.47	6.1	8.43	2.13	2.62
3	15.58	20.22	6.3	7.09	2.16	2.57
5	11.15	22.43	7.0	5.02	2.22	2.51
7	9.53	23.68	7.3	4.22	2.26	2.51

Fired modulus of rupture:

Cone 1, 3,303 pounds per square inch.

Cone 7, 4,171 pounds per square inch.

Fired specific impact strength:

Cone 2, 1.98 centimeter kilograms per square centimeter.

Cone 7, 1.29 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 7, 14,168 pounds per square inch.

Best firing range: Cone 06 to cone 7.

Overfiring temperature: Not determined.

Pyrometric cone equivalent: Cone 17-18.

Scumming: Scum occurs on all trials fired to cone 5 and lower but scum is not apparent on trials fired above cone 5. Six pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The glaze produced at 2,100°F. is a brownish green on a gray colored background while that produced at 2,050°F. has a light brown color. When $BaCO_3$ is added the glaze produced at 2,050°F. has a chocolate brown color.

Utilization: This shale was used for the production of sewer pipe. It can be utilized also for the manufacture of drain tile and hollow tile. The fired material has a reddish tan color with white particles interspersed through the mass.

In Trumbull and Mahoning counties the Anthony horizon is generally drift covered. The shale has not been utilized for ceramic purposes.

Massillon Shale

Over many square miles of the outcrop areas of lower Pottsville there is a massive sandstone overlying the Quakertown No. 2 coal horizon which is known in Ohio geology as the Massillon sandstone. Sandstone in greater or less state of development characterizes this horizon entirely across the State from the Ohio River in Scioto County on the south to the Pennsylvania State line in Trumbull and Mahoning counties on the east. It probably reaches its best development on the outcrop from Muskingum County north through Coshocton, Holmes, eastern Wayne, western Stark, and northwestern Tuscarawas counties. This stone has been used at various times near Massillon, Dundee, and Beach City. In the last two counties it is used as a quarry stone. Elsewhere in the outcrop areas the sandstone may be massive, may thin or pass into sandy shale, or the base of the sandstone may be separated from the Quakertown coal by a shale interval of variable thickness. The shale equivalent of the Massillon sandstone is known in these pages as the Massillon shale.

Massillon shale of somewhat variable character is present in Scioto, Jackson, Vinton, Hocking, Perry, and Muskingum counties, but it has been utilized for the manufacture of ceramic products chiefly in Summit County.

In Scioto County the horizon of the Massillon shale passes through Green, Porter, and Bloom townships, where the interval from the Bear Run coal, which forms the top of the shale series, to the Quakertown coal below averages about 35 feet. Both sandstone and shale are present on this horizon. The general conditions are illustrated by the following measurements on the William Tripp property in Section 4, Bloom Township:[1]

		Ft.	In.
Coal blossom, *Bear Run*		..	6
Clay shales, dark		3	6
Shales, gray and parts covered	*Massillon*	28	0
Sandstones, flaggy and medium bedded	*Massillon*	13	0
Coal outcrop, *Quakertown*		1	8
Shales and covered	*Anthony*	33	0
Sandstones	*Anthony*	7	0
Coal, *Anthony*		..	2
Clay, flint, dark, *Sciotoville*		6	0

The Massillon shale has not been utilized in Scioto County. The horizon of the Massillon shale in Jackson County is similar to that of Scioto County in that both sandstone and shale are present but the sandstone phase is more pronounced and in some localities, notably at places in Washington Township, the sandstone has entirely replaced the Quakertown coal.

The sandstone is irregular in extent for in one locality it may appear massive and a short distance away it may be represented by shaly sandstone or sandy shale. The thickness of this member varies 20 to 30 feet. Outcrops are due along a north-south belt extending from Scioto and Hamilton townships to Washington Township. From Jackson County the outcrops of the Massillon horizon pass north through Vinton County where it is represented by massive sandstone. This sandstone attains a thickness of 20 to 60 feet and in some localities replaces the beds both above and below it. In Swan Township at the north edge of Vinton County, the sandstone phase is only locally developed for at some localities shale is the chief deposit on the Massillon horizon. The following record reported by Wilber Stout shows the thickness of beds and their succession in Section 8, Swan Township:

	Ft.	In.
Shale, gray	12	0
Coal, *Bear Run*	1	4
Clay, impure	..	6
Shale, gray, siliceous, *Massillon*	12	0
Coal, good, *Quakertown*	3	0
Clay, siliceous	1	0

The belt of Massillon outcrops passes northeast from Swan and Jackson townships, Vinton County, across Hocking County into southwestern Perry County. Near Somerset in Reading Township, Perry County, shale on the Massillon horizon is being used extensively by the Belden Brick Co. for the manufacture of face brick. This plant, located on the Baltimore and Ohio railroad about one mile northeast of town,

[1] Geol. Survey Ohio, 4th Ser., Bull. 20, pp. 551-552, 1916.

has a daily capacity of about 65,000 brick, which are graded for the market into nine shades. The record given below was secured in the pit near the plant:

	Ft.	In.
Shale, micaceous, sandy	14	0
Shale, gray, ferruginous, somewhat sandy	16	0
Shale, dark, carbonaceous, ferruginous, sandy	1	6
Shale, ferruginous, sandy	3	6
Sandrock, gray, argillaceous, fine-grained	7	0
Shale, gray at bottom becoming more blue and sandy upward	16	0
Shale, reddish brown	2	0
Shale, bluish gray	2	0
Shale, gray, sandy	5	2

The bottom of this pit lies about 115 feet below the Lower Mercer limestone exposed along the road about ⅜ of a mile southwest of the plant. While some doubt may exist as to the exact correlation of the shale described in the above section, due to the lack of exposure of key beds, it is here considered to be Massillon shale. A sample of shale was cut from this pit on July 20, 1929 and submitted for analysis and tests.

Sample No. 13

Tests of Massillon shale from pit of the Belden Brick Company, Somerset, Perry County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	0.77
Water, combined, H_2O+	4.25
Silica, SiO_2	68.92
Alumina, Al_2O_3	14.78
Titanic oxide, TiO_2	0.97
Phosphorus pentoxide, P_2O_5	0.08
Ferric oxide, Fe_2O_3	4.15
Ferrous oxide, FeO	2.20
Lime, CaO	0.24
Magnesia, MgO	0.77
Sodium oxide, Na_2O	0.04
Potassium oxide, K_2O	2.40
Manganese oxide, MnO	0.05
Sulphur, S	0.01
Carbon dioxide, CO_2	0.12
Carbon, organic, C	0.30

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .162 \\ Na_2O & .003 \\ CaO & .016 \\ MgO & .052 \\ FeO & .402 \\ MnO & .003 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 4.663 \\ TiO_2 & 0.066 \\ P_2O_5 & 0.005 \end{array}\right.$$

$$RO \quad .638$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has average plasticity. A featheredged column is extruded from the die.

Time of slaking: **13.80 minutes.**

Water of plasticity: **18.16 per cent.**

Dry shrinkage:
Volume: 10.85 per cent.
Linear: 3.49 per cent.
Drying behavior: The material dries satisfactorily with ordinary care.
Dry modulus of rupture: 296 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	26.00	5.06	1.7	13.40	1.94	2.63
04	22.16	7.83	2.5	11.05	2.00	2.57
02	21.11	10.36	3.4	10.24	2.07	2.62
1	18.91	12.63	4.0	8.94	2.13	2.61
3	15.85	14.37	4.6	7.33	2.17	2.57
5	13.10	15.81	5.0	5.92	2.21	2.54
7	10.68	18.63	5.9	4.72	2.27	2.54

Fired modulus of rupture:
Cone 1, 2,033 pounds per square inch.
Cone 7, 2,960 pounds per square inch.
Fired specific impact strength:
Cone 2, 1.32 centimeter kilograms per square centimeter.
Cone 7, 1.27 centimeter kilograms per square centimeter.
Fired crushing strength:
Cone 7, 10,846 pounds per square inch.
Best firing range: Cone 06 to cone 7.
Overfiring temperature: Cone 9.
Pyrometric cone equivalent: Cone 14-15.

Scumming: Scum occurs on all trials fired to cone 2 and lower, but no scum is apparent on trials fired above cone 2. Three pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: A good salt glaze is produced at 2,100° F. The color is a brownish-green on a pink background. At 2,050°F. a good glaze is produced the color of which is an intermingling of gray and brown shading to a solid brown. When $BaCO_3$ is added, the glaze produced at 2,100°F. has a dark grayish-brown color.

Utilization: This shale was being used for the manufacture of face brick and since it does not have the requisite plasticity for hollow tile or drain tile, this use is about the only possibility except for common brick. The fired material develops a good red color at about cone 2.

The Massillon horizon in Muskingum County outcrops in Jackson, Licking, Cass, Newton, Hopewell, and Falls townships, all of which are located in the western half of the county. Throughout Licking, Jackson, and Cass townships the Massillon is a heavy massive sandstone which lies close above the Quakertown coal and which in some localities extends upward and replaces overlying members. In Newton and Hopewell townships the sandstone is more thin and local in its development, and shale becomes more prominent on the Massillon horizon. The following section by Wilber Stout shows the succession near Poverty Run school, Hopewell Township, where the Massillon shales are well developed:

		Ft.	In.
Shales, dark, *Vandusen* coal horizon		1	0
Clay, dark, siliceous		2	0
Shale and covered		7	0
Coal blossom, *Bear Run*		..	6
Clay, siliceous		2	6
Shale, sandy in part	*Massillon*	15	0
Sandstone, ferruginous, conglomeratic	*Massillon*	..	8
Clay, dark, shaly, *Quakertown*		2	4

In Hopewell Township, Licking County, shale is likewise developed on the Massillon horizon.

The Massillon horizon is due above drainage in the eastern and southeastern parts of Wayne County, but the region is drift covered and few rock exposures are found. Drill records show sandstone and shale above the Quakertown coal.

The outcrop of the Massillon shale is due to extend across the southern and eastern parts of Summit County, but the mantle of glacial drift obscures most of the exposures. At Barberton the shales which lie both above and below the Quakertown coal horizon are utilized in Plant No. 25 of the American Vitrified Products Co. for the manufacture of sewer pipe with good results. The Massillon shale constitutes about one-fourth of the raw materials utilized. In the south part of Akron, shale which is probably Massillon in age is used by L. W. Camp Co. for the manufacture of building tile, by the Crouse Clay Products Co. for sewer pipe, and also at Plant No. 10 of the Robinson Clay Products Co. for sewer pipe. Along the Little Cuyahoga River Valley in northern Springfield Township, the Massillon shale is regularly used at the plant of Camp Bros. Co., located a short distance west of Mogadore, for the production of common brick and building tile. A description of the exposure in the pit is given below:

		Ft.	In.
Glacial drift, yellowish, estimated thickness		10	0
Clay shale, gray		1	0
Shale, bluish gray, somewhat sandy	*Bear Run*	3	6
Sandrock, yellowish-gray, fine-grained	*Bear Run*	2	0
Coal, shaly, *Bear Run*		1	0
Clay shale, bluish gray	*Massillon*	2	0
Shale, bluish gray, sandy	*Massillon*	3	0
Sandrock	*Massillon*	5	8
Smut streak, *Quakertown No. 2*		..	3
Clay, gray, a little sandy	*Anthony*	4	8
Shale, dark, carbonaceous, a little sandy	*Anthony*	12	2

The material used in the plant includes shale, sandrock, clay, and glacial drift in the proportions as delivered by the shovel. A sample was cut at this place for testing. The sample included all materials exposed in the pit with the exception of the coals and glacial drift. The results of the tests appear below:

Sample No. 14

Tests of Anthony, Massillon, and Bear Run shales from pit of Camp Bros. Company, Mogadore, Summit County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	0.78
Water, combined, H_2O+..	5.27
Silica, SiO_2	60.62
Alumina, Al_2O_3	18.14
Titanic oxide, TiO_2	1.06
Phosphorus pentoxide, P_2O_5	0.11
Ferric oxide, Fe_2O_3	2.05
Ferrous oxide, FeO	4.10
Lime, CaO	0.32
Magnesia, MgO	1.72
Sodium oxide, Na_2O	0.10
Potassium oxide, K_2O	2.35
Manganese oxide, MnO	0.06
Ferrous sulphide, FeS_2	0.38
Sulphur trioxide, SO_3	0.25
Carbon dioxide, CO_2	1.85
Carbon, organic, C	1.01

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .129 \\ Na_2O & .005 \\ CaO & .018 \\ MgO & .095 \\ FeO & .340 \\ MnO & .003 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.342 \\ TiO_2 & 0.058 \\ P_2O_5 & 0.006 \end{array}\right.$$

$$RO \quad .590$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material is plastic. A very good column is extruded from the die.

Time of slaking: **11.1 minutes.**

Water of plasticity: **19.43 per cent.**

Drying shrinkage:

Volume: **10.89 per cent.**

Linear: **3.50 per cent.**

Drying behavior: The material dries satisfactorily with ordinary care.

Dry modulus of rupture: 273 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	24.17	11.36	3.6	12.06	2.00	2.64
04	16.81	15.30	4.9	8.04	2.10	2.52
02	15.06	17.15	5.4	7.06	2.14	2.51
1	12.82	19.72	6.2	5.83	2.20	2.52
3	10.19	21.91	6.8	4.49	2.26	2.52
5	7.62	23.00	7.2	3.29	2.31	2.50
7	9.01	18.85	5.9	4.14	2.18	2.39

Fired modulus of rupture:
Cone 04, 3,155 pounds per square inch.
Cone 5, 3,104 pounds per square inch.
Fired specific impact strength:
Cone 05, 1.37 centimeter kilograms per square centimeter.
Cone 4, 1.25 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 5, 13,249 pounds per square inch.
Best firing range: Cone 06 to cone 5.
Overfiring temperature: Cone 7.
Pyrometric cone equivalent: Cone 14-15.

Scumming: Scum occurs on all trials fired to cone 5 and lower but scum is not apparent on trials fired above cone 5. Four pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: A good salt glaze is produced at both 2,100°F. and 2,050°F. The color of the glaze produced at 2,050°F. is a greenish brown mottle shading into dark brown, while the color produced at 2,100° is a brownish green on a pinkish gray background. When $BaCO_3$ is added the color of the glaze produced at 2,100°F. is a brown with some white spots showing through it.

Utilization: This shale was being used for the production of common brick. Its physical properties suggest that this shale can be used also for face brick, paving brick, hollow tile, and drain tile. The fired material has a stony structure. A good red color is developed at cone 1.

From Summit County the belt of outcrops of the Massillon shale horizon extends to the west into southeastern Medina County and to the east through Portage, southern Trumbull, and northern Mahoning counties. The shales are not utilized at any place in this area for the manufacture of ceramic products; and as the region is drift covered and few natural exposures occur, there is little definite knowledge concerning the character of the Massillon horizon.

Bear Run Shale

The Bear Run shale horizon is defined by the Bear Run coal and clay beds beneath and the Vandusen clay and coal above. This sandstone and shale member in Ohio varies from about 20 to 60 feet but averages about 30 feet. The Bear Run shale is best defined along the outcrop from the Ohio River in Scioto County north through Jackson and Vinton to eastern Licking and western Muskingum counties where the Bear Run and Vandusen coals are generally present. In northeastern Ohio the Bear Run shale horizon is not clearly outlined as the region is drift covered and as few rock exposures occur. The only place in Ohio where the Bear Run shale is being utilized at the present time is near Mogadore, Springfield Township, Summit County, where material overlying the Bear Run coal together with the Massillon and Anthony shales below are worked by Camp Bros. Co. for the production of common brick and building tile.

In Scioto County the Bear Run horizon outcrops over a narrow north and south belt extending through Green, Porter, Vernon, and Bloom townships. Both sandstone and shale are present, the sandstone in some localities being massive and extending down to the Bear Run. Locally a thin iron ore is found embedded in the shale lying close above the Bear Run coal. The average thickness of the Bear Run shale and sandstone horizon in Scioto County is about 30 feet. The following record of outcrops from Section 16, Bloom Township, illustrates the nature of the succession:[1]

		Ft.	In.
Coal, *Vandusen*, reported thickness		2	3
Shales	*Bear Run*	8	0
Sandstone	*Bear Run*	11	0
Shale	*Bear Run*	3	0
Sandstone	*Bear Run*	5	0
Covered	*Bear Run*	27	0
Coal, *Bear Run*, reported thickness		1	5

The general aspects of the Bear Run member in Jackson County are similar to those of Scioto County. Both shale and sandstone are present although the proportions vary from one locality to another. In northern Coal and Washington townships the horizon of the Bear Run member is occupied chiefly by massive sandstone which in some localities replaces the underlying Bear Run coal. Outcrops of the Bear Run horizon are also found in Hamilton, Scioto, Lick, Liberty, Franklin, and Jefferson townships.

The Bear Run horizon in Vinton County is occupied by sandstone and shale which outcrop in Eagle, Harrison, Swan, Elk, Jackson, and Richland townships. The sandstones are generally local in their occurrence for they tend to grade laterally within a short distance along the outcrop into shale, only to reappear again at a more distant locality. At many places dark shales are found immediately overlying the Bear Run coal, which are rich in iron carbonate nodules.

From Vinton County the Bear Run horizon outcrops over a belt extending through eastern Hocking and central Perry counties where the member consists of sandstone and shale. In Muskingum County the Bear Run horizon is present in Newton, Hopewell, Falls, Licking, Jackson, western Muskingum, and western Cass townships. The member consists of both sandstone and shale, but the latter is usually local and patchy in its distribution. Neither the Bear Run coal below nor the Vandusen coal above is well developed, and in some localities their horizons are not well marked. The following section of exposures located about one mile west of Pleasant Valley in the southern part of Licking Township illustrates the general sequence and thickness of the beds.[2]

[1] Geol. Survey Ohio, 4th Ser., Bull. 20, p. 560, 1916.
[2] Stout, Wilber, Geol. Survey Ohio, 4th Ser., Bull. 21, p. 61, 1918.

		Ft.	In.
Coal, cannel, bony, *Vandusen*		..	6
Shale, dark, hard	*Bear Run*	1	0
Covered		2	6
Sandstone, shaly		2	0
Shale, siliceous		2	0
Covered		3	0
Shale and covered		10	2
Shale with iron ore nodules		1	0
Coal, bright, hard, *Bear Run*		..	10
Sandstone, massive, conglomeratic, *Massillon*		15	0
Coal, cannel, bony	*Quakertown*	..	9
Shale, black, with thin coal bands		..	10

Much the same conditions exist on the Bear Run shale horizon in eastern Licking County as are found in adjacent areas in Muskingum County.

Vandusen Shale

The Vandusen shale horizon extends from the top of the Vandusen coal upward to the bottom of the Lower Mercer coal. No prominent sandstone members occur on this horizon although local deposits of sandstone may be present. Over small areas in Muskingum, Coshocton, and Mahoning counties, a thin limestone or iron ore, a few inches in thickness and known as the Lowellville or Poverty Run, is present closely overlying the Vandusen coal. The strata which occupy this horizon show considerable variation in thickness from place to place but the average for the State as a whole is about 24 feet. The Vandusen shale horizon is fairly well defined along the extent of its outcrop from Scioto County to Muskingum. North of Muskingum County the horizon is not clearly shown, due in part to a lack of detailed information in some localities and in part to the mantle of glacial drift which covers the outcrops.

In Scioto County the outcrops of the Vandusen shale horizon are found in Green, Vernon, Porter, and Bloom townships. Both sandstone and shale are present but the sandstone is rather thin and local in its development. Where the sandstones are wanting the shales which take their place are possible sources for brick materials. The following record from Section 22, Bloom Township, illustrates the stratigraphic succession:[1]

		Ft.	In.
Coal, *Lower Mercer*		1	6
Shale and covered	*Vandusen*	18	0
Coal blossom		..	6
Shale		5	0
Shale and covered		8	0
Coal, *Vandusen*, reported thickness		1	3

[1] Stout, Wilber, Geol. Survey Ohio, 4th Ser., Bull. 20, p. 560, 1916.

From northeastern Scioto County the belt of outcrops of the Vandusen shale horizon extends across western Jackson, where it is characterized by both sandstone and shale in proportions which vary with the locality. South of Jackson in Lick Township, the thickness of the shale ranges from 15 to 30 feet but north of town, massive sandstone occurs which locally replaces the Vandusen coal. Much the same conditions of lithology are found in central Vinton, eastern Hocking, and central Perry counties, through which the outcrops of the Vandusen horizon extend.

In Muskingum County the Vandusen horizon outcrops through Hopewell, Newton, Licking, Jackson, Cass, Jefferson, and Madison townships, where the thickness of the bed ranges from about 20 to 30 feet. Both sandstone and shale phases are represented, the sandstone being well developed in Jackson, Cass, and Falls townships. Vandusen shales have not been utilized in Muskingum County for ceramic purposes.

Flint Ridge and Lower Mercer Shales

The Flint Ridge and Lower Mercer shales occur in the interval extending from the Lower Mercer coal upward to the Middle Mercer clay. The Lower Mercer shale occupies the lower part of this interval above which in ascending order are the Flint Ridge clay and coal and the Flint Ridge shale. Near the base of the Lower Mercer shale is the Boggs iron ore which is local in extent. Of the two shale horizons the Flint Ridge is of the less importance as it is generally the thinner of the two and as it is wanting over large areas. The Flint Ridge coal and clay horizons which separate the two shales are rather wide spread in extent but the coal and overlying shale disappear in many places and the Flint Ridge clay is found immediately below the Middle Mercer clay from which it cannot be readily distinguished. The belt of outcrops of Flint Ridge and Lower Mercer shales in Ohio extends from Lawrence and Scioto counties on the south, through Jackson, Vinton, Hocking, Perry, Muskingum, Licking, Coshocton, Holmes, Tuscarawas, Wayne, Stark, Summit, and Portage counties to the State line in Mahoning County. Considering the outcrops as a whole, the average interval from the Lower Mercer coal to the Middle Mercer clay is about 16 feet.

In Scioto County outcrops of the Lower Mercer shale horizon are present in Green, Vernon, and Bloom townships. The horizon is composed chiefly of shale as sandstone deposits are thin and local in their occurrence and as the Flint Ridge coal and clay are more often wanting than present. The Middle Mercer coal and clay, which form the top of this shale member, are poorly developed as is also the Lower Mercer limestone which immediately overlies the coal. The Little Red Block ore lies close above the limestone where both are present, and as it is persistent throughout the county, it forms a good bench for reference. The average interval from the Lower Mercer coal to the Little Red Block ore in Scioto County is about 45 feet. The general stratigraphic relations are indicated in the following record from Section 25, Bloom Township:[1]

		Ft.	In.
Coal, *Webster Block*		1	6
Clay		3	0
Covered		8	6
Ore, *Little Red Block* or *Lower Mercer*		..	4
Shale and covered	*Lower Mercer*	43	0
Sandstone, plant marked	*Lower Mercer*	1	0
Iron ore	*Lower Mercer*	1	0
Shale	*Lower Mercer*	3	0
Coal blossom, *Lower Mercer*		1	0

The Lower Mercer shales were formerly used by the Webster Brick Co. of South Webster, now known as the Portsmouth Clay Products Co., for the manufacture of face brick. The shale worked well and produced a brick of good quality. The character and thickness of the beds exposed in the pit and on the hillside above it are shown in the following record:

		Ft.	In.
Coal blossom, *Upper Mercer*		..	9
Clay, gray, siliceous		9	0
Shale and covered		16	6
Clay, gray, plastic, *Middle Mercer*		1	0
Shale, gray, arenaceous	*Lower Mercer*	6	6
Shale, dark, bluish-gray, micaceous	*Lower Mercer*	4	0
Shale, dark, sandy	*Lower Mercer*	5	0
Iron ore, nodular	*Lower Mercer*	..	6
Shale, gray, micaceous	*Lower Mercer*	10	6
Shale, sandy, ferruginous	*Lower Mercer*	2	10
Shale, gray, sandy	*Lower Mercer*	2	2
Shale, black, carbonaceous, micaceous	*Lower Mercer*	..	6
Clay shale, bluish-gray	*Lower Mercer*	7	7

The Lower Mercer coal is reported to be present a few feet below the bottom of the pit. The material formerly utilized at this plant included all the materials recorded in the above section below the Middle Mercer clay with the exception of the 6-inch layer of nodular iron ore and the thin bed of dark carbonaceous shale exposed near the bottom of the pit.

A sample of Lower Mercer shale was taken on June 19, 1929, and submitted for analysis and physical tests. The results of the tests are given below:

[1] Geol. Survey Ohio, 4th Ser., Bull. 20, p. 566, 1916.

Sample No. 19

Tests of Lower Mercer shale from pit of Portsmouth Clay Products Company, South Webster, Scioto County

Chemical analysis

Water, hydroscopic, H_2O-	0.76
Water, combined, H_2O+...	...
Silica, SiO_2..............	56.64
Alumina, Al_2O_3............	18.33
Titanic oxide, TiO_2........	1.30
Phosphorus pentoxide, P_2O_5	0.31
Ferric oxide, Fe_2O_3........	8.70
Ferrous oxide, FeO........	...
Lime, CaO................	0.66
Magnesia, MgO...........	2.09
Sodium oxide, Na_2O.......	0.78
Potassium oxide, K_2O.....	3.92
Manganese oxide, MnO....	trace
Sulphur trioxide, SO_3......	...

Analysis by U. S. Bureau of Mines

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .214 \\ Na_2O & 042 \\ CaO & .036 \\ MgO & .114 \\ FeO & .427 \\ MnO & \ldots \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.090 \\ TiO_2 & 0.071 \\ P_2O_5 & 0.016 \end{array}\right.$$

$$RO \quad .833$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has rather short plasticity. A very good column is extruded from the die.

Time of slaking: Over 24 hours.

Water of plasticity: 20.18 per cent.

Dry shrinkage:

Volume: 8:06 per cent.

Linear: 2.62 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 342 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	26.38	13.18	4.2	13.19	2.00	1.72
04	17.80	19.26	6.0	8.33	2.15	2.61
02	12.75	23.37	7.3	5.70	2.26	2.59
1	9.06	26.29	8.1	3.85	2.34	2.53
3	6.72	28.00	8.6	2.80	2.39	2.40
5	3.98	27.20	8.3	1.67	2.40	2.49
7	6.79	23.50	7.0	3.10	2.28	2.36

Fired modulus of rupture:

Cone 04, 2,248 pounds per square inch.

Cone 4, 3,714 pounds per square inch.

Fired specific impact strength:

Cone 05, 1.28 centimeter kilograms per square centimeter.

Cone 4, 1.22 centimeter kilograms per square centimeter.

Fired crushing strength:

Cone 4, 14,881 pounds per square inch.

Best firing range: Cone 06 to cone 4.

Overfiring temperature: Cone 5.

Pyrometric cone equivalent: Cone 11-12.

Scumming: Scum occurs on all trials fired to cone 3 and lower but scum is not apparent on trials fired above cone 3. Three pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: A good salt glaze is produced at 2,100°F., the color being a reddish brown with some gray mottling. The glaze produced at 2,050°F. has some pimples and is dead looking. When $BaCO_3$ is added a glaze is not produced at 2,100°F.

Utilization: This shale was not being utilized. Possibilities for utilization consist of common brick, face brick, hollow tile, and drain tile. The fired material has a stony structure. A good red color is developed at cone 02.

The Lower Mercer shale horizon in Lawrence County is above drainage in southern Hamilton, western Elizabeth, and northwestern Washington townships. Both shale and sandstone are represented. The shale in some localities is of sufficient thickness and of such a quality that it is adapted to the manufacture of brick. The following section secured by Wilber Stout north of Kelly's Mills in Elizabeth Township shows the general stratigraphic relations:

	Ft.	In.
Limestone, *Lower Mercer*	1	0
Shales	18	0
Coal blossom	..	6
Clay shale	1	6
Sandstone	4	0
Covered	4	6
Coal, *Lower Mercer*	1	6

Extending northward from Scioto County, the Lower Mercer shale horizon passes through central Jackson County where it appears above drainage in parts of Hamilton, Scioto, Franklin, Lick, Coal, Milton, and Washington townships. The base of this shale and sandstone member is well defined for the Lower Mercer coal is generally present throughout the area, but the top is less definite as the Middle Mercer coal is generally wanting and as the Lower Mercer limestone is only developed in the northern part of the county. The Lower Mercer horizon in Jackson County is composed of both sandstone and shale with an average thickness of about 45 feet. Materials from this horizon have never been utilized in this county.

In Vinton County the horizon of the Lower Mercer shale comes to the surface in Brown, Swan, Jackson, Elk, Richland, and Clinton townships. Both sandstone and shale are present with an average thickness of about 23 feet. At a few localities in Richland and Elk townships the Flint Ridge horizon is represented by a thin coal and clay lying a few feet below the Middle Mercer clay. Shales are well developed on the Lower Mercer horizon in portions of Jackson, Richland, Elk, and Swan townships. Wilber Stout secured the following record from Section 29, Richland Township, which illustrates the stratigraphic relations of this shale bed:

	Ft.	In.
Coal, *Middle Mercer*	..	3
Clay shale and covered	6	9
Coal, smut streak in clay	..	3
Clay	1	0
Shale and covered, *Lower Mercer*	37	9
Coal blossom, *Lower Mercer*	2	0
Clay	2	0

The Lower Mercer horizon in Hocking County is present above drainage in parts or all of Benton, Washington, Starr, Falls, Green, Marion, and Falls Gore townships. In this area shale is the predominating type of rock between the Lower Mercer and the Middle Mercer coals although local deposits of sandstone have been recognized in Marion, Falls Gore, Green, and Starr townships. The Flint Ridge clay is generally present but at some localities it coalesces with the Middle Mercer clay and at other places it lies close below it. The Lower Mercer shales have not been utilized for ceramic purposes in Hocking County.

Much the same conditions exist on the Lower Mercer shale horizon in Perry County as are found in Hocking County. In Licking County outcrops of this horizon are confined to Hopewell Township, where sandstone is present below the Middle Mercer clay.

In Muskingum County the Lower Mercer shales are wide spread in their distribution for their outcrops are present in Newton, Hopewell, Springfield, Falls, Licking, Muskingum, Jackson, Cass, Jefferson, Washington, and Madison townships. The average thickness of the bed, including the Flint Ridge coal and clay which are well represented in this county, is about 21 feet. Both shale and sandstone are present but the latter is generally somewhat shaly in character. Shale from this horizon is worked to a limited extent by the Fultonham Texture Brick Co. located at Fultonham in Newton Township, where it is used for the production of face brick. The general stratigraphy of the member is illustrated by the following record secured by Mr. Stout in Section 20, Newton Township:

		Ft.	In.
Limestone, *Lower Mercer*		1	2
Shale, dark		..	4
Coal, *Middle Mercer*		..	4
Clay, light, siliceous		2	0
Shale and shaly sandstone		6	9
Coal, *Flint Ridge*		..	1
Clay, light, plastic		3	0
Sandstone, shaly	*Lower Mercer*	2	0
Sandstone	*Lower Mercer*	3	0
Shale and covered	*Lower Mercer*	8	0
Shale, dark, carbonaceous, *Lower Mercer* coal horizon		1	0
Clay, light, siliceous		4	0

The Boggs horizon, which may be represented by an iron ore, limestone, flint, or fossiliferous shale, is rather wide spread in Muskingum County, but as it lies close above the Lower Mercer coal and is everywhere thin, its presence is of little detriment to Lower Mercer shales.

The Lower Mercer shale horizon outcrops near the summit of the hills and ridges in the southeastern part of Knox County. As the areal extent of the beds is small, the deposits have little value. In Coshocton County, which is the next county north of Muskingum, the horizon of the Lower Mercer shale is of wide extent for it outcrops in Pike, Washington, Virginia, Franklin, Perry, Bedford, Jackson, Tuscarawas, Lafayette, Oxford, New Castle, Jefferson, Bethlehem, Keene, Clark, Mill Creek, Monroe, and Tiverton townships. The best exposures are found in the western part of the county where the horizon is near the hilltops. Both sandstone and shale are present and the Flint Ridge clay and coal are found in some localities. The shale has not been utilized in this county.

Outcrops of the Lower Mercer shale horizon in Tuscarawas County are confined to the northern part where exposures are present along South Fork in Wayne and Sugar Creek townships, along Sugar Creek in Franklin Township, and along the Tuscarawas River in Lawrence Township. Here the beds show much the same characteristics as in Coshocton County. To the west and northwest of Tuscarawas County the Lower Mercer shale horizon is exposed in Mechanic, Killbuck, Richland, Walnut Creek, Berlin, Hardy, Monroe, Knox, Paint, Salt Creek, and Prairie townships in Holmes County and in Paint, Sugar Creek, and Baughman townships in Wayne County. Conrey reports the following succession in Section 24, Baughman Township, Wayne County:[1]

	Ft.	In.
Drift	15	0
Limestone, *Lower Mercer*	2	6
Clay	1	6
White soapstone	11	0
Gray shale	15	0
Sandy shale	2	0
Gray shale	25	0
White soapstone	6	0
Gray shale	20	0
Coal smut and fire clay, *Quakertown*, No. 2	..	3
Gray shale	20	0
Black band shale	2	0
Dark gray rock	13	0
Soft dark shale, *Sharon* coal horizon	..	6
Gray rock	29	6

The Lower Mercer coal, which marks the base of the Lower Mercer shale horizon, has not been definitely recognized in Wayne County.

The Lower Mercer shale horizon lies near the surface over much of

[1] Geol. Survey Ohio, 4th Ser., Bull. 24, pp. 101-102, 1921.

the northern and western part of Stark County but due to the thick deposits of glacial drift in this region few exposures occur. Perhaps the best outcrops are found along the Tuscarawas River Valley south of Massillon and along Nimishillen Creek south of Canton. The Lower Mercer shale has been utilized for the manufacture of drain tile and building block at the plant owned by the Dalton Clay Products Co. and located at East Greenville, Tuscarawas Township. In 1929 this plant was being operated by Derr and Co. of Massillon. The exposures in the pit are described in the following record:

		Ft.	In.
Limestone, bluish gray, *Lower Mercer*		1	3
Coal, *Middle Mercer*		1	0
Clay, ferruginous, siliceous		4	0
Shale, yellowish, ferruginous, very sandy	*Lower Mercer*	2	6
Shale, bluish gray, sandy	*Lower Mercer*	5	0

The shale underlying the Middle Mercer clay in this pit was sampled for chemical analysis and other tests on August 9, 1929. The results are as follows:

Sample No. 18

Tests of Lower Mercer shale from pit of Dalton Clay Products Co., East Greenville, Stark County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	0.40
Water, combined, H_2O+	4.88
Silica, SiO_2	66.66
Alumina, Al_2O_3	14.28
Titanic oxide, TiO_2	0.83
Phosphorus pentoxide, P_2O_5	0.12
Ferric oxide, Fe_2O_3	1.95
Ferrous oxide, FeO	3.03
Lime, CaO	0.72
Magnesia, MgO	1.68
Sodium oxide, Na_2O	0.47
Potassium oxide, K_2O	2.46
Manganese oxide, MnO	0.05
Sulphur trioxide, SO_3	0.12
Ferrous sulphide, FeS_2	0.47
Carbon dioxide, CO_2	0.85
Carbon, organic, C	1.19

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .172 \\ Na_2O & .033 \\ CaO & .050 \\ MgO & .118 \\ FeO & .355 \\ MnO & .003 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 4.668 \\ TiO_2 & 0.058 \\ P_2O_5 & 0.008 \end{array}\right.$$

RO .731

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has rather poor plasticity. A featheredged column is extruded from the die.

Time of slaking: 13.00 minutes.

Water of plasticity: 17.42 per cent.

Dry shrinkage:

Volume: 8.08 per cent.

Linear: 2.60 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 281 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	29.27	5.53	1.8	15.72	1.81	2.64
04	25.67	9.73	3.1	13.28	2.03	2.60
02	23.81	13.36	4.3	11.86	2.05	2.64
1	21.39	15.85	5.0	10.32	2.07	2.64
3	18.23	17.13	5.4	8.63	2.11	2.60
5	14.88	18.32	5.8	6.89	2.15	2.54
7	12.87	18.51	5.8	6.00	2.14	2.46

Fired modulus of rupture:
Cone 04, 1,338 pounds per square inch.
Cone 6, 2,123 pounds per square inch.
Fired specific impact strength:
Cone 05, 1.42 centimeter kilograms per square centimeter.
Cone 4, 1.29 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 5, 13,308 pounds per square inch.
Best firing range: Cone 06 to cone 7.
Overfiring temperature: Cone 7.
Pyrometric cone equivalent: Cone 12-13.
Scumming: Scum is not apparent on any trials fired.
Salt glazing: The glaze produced at 2,100°F. is a yellowish green on a gray-colored background. The glaze produced at 2,050° F. is a dark yellowish green brown mottle.
Utilization: This shale was being used for the production of building tile. As the material is short for the production of this product it is better adapted for the manufacture of face brick or common brick. On firing the material develops a good red color at cone 02.

Some two miles south of Massillon, in Section 30, Perry Township, shales below the Lower Mercer limestone have been utilized to a small extent by the Massillon Brick and Tile Co., now owned by the Velvet Brick Co. The exposures in the pit as measured by Wilber Stout are as follows:

		Ft.	In.
Limestone, *Lower Mercer*		1	2
Clay, part covered		8	0
Sandstone, shaly		5	0
Coal	*Flint Ridge*	..	7
Shale	*Flint Ridge*	..	3
Coal	*Flint Ridge*	..	3
Sandstone, clay-bonded, plant marked		5	0
Shale, dark gray		2	6
Sandstone, hard, dark gray		1	8
Shale		11	0
Sandstone		2	6
Shale		3	0
Sandstone		8	6
Shale, bony, dark, *Lower Mercer* coal horizon		2	6
Clay, dark		2	0
Shale, bluish-gray		10	0

	Ft.	In.
Shale	8	0
Shale, black, *Vandusen* coal horizon	..	8
Clay, light, siliceous	5	0
Clay, dark gray	8	0

The clay-bonded sandrock below the Flint Ridge coal is used together with the underlying shales for the production of face brick and building block.

The Lower Mercer shale is due a little above drainage level along Nimishillen Creek in Pike Township, but the material has not been utilized for ceramic purposes. This horizon is likewise due above drainage over a large area including portions of northern Stark, southeastern Summit, central and southern Portage, and the northern two-thirds of Mahoning County. Little is known about the Lower Mercer shale in this area as the region is drift covered and as the valleys, with the exception of the Mahoning Valley, are shallow and therefore provide few exposures. The general succession along the Mahoning Valley in Mahoning County is illustrated by the following description of outcrops exposed along Furnace Hollow at Lowellville in Poland Township:

		Ft.	In.
Limestone, *Upper Mercer*		2	10
Coal, shaly	*Bedford*	..	11
Parting		..	2
Coal		..	4
Clay, dark, with shaly coal bands		1	1
Clay, plastic		1	6
Shaly sandstone and covered		13	3
Shale, gray		5	0
Ore		..	3
Limestone	*Lower Mercer*	2	1
Limestone		..	6
Clay, dark	*Middle Mercer*	..	8
Clay, light, siliceous		2	0
Clay, shaly, siliceous		4	0
Coal, shaly, *Flint Ridge*		..	5
Clay, siliceous with iron ore nodules		5	3
Shale, dark, fissile, carbonaceous		2	6
Shale, soft, light gray color		4	0
Coal, *Lower Mercer*		1	11
Clay, siliceous, with ore nodules		5	0

Middle and Upper Mercer Shales

The Middle Mercer and Upper Mercer shales include the shale beds which lie between the Lower Mercer limestone below and the Bedford clay above. Both the overlying clay and underlying limestone are persistent over the outcrop areas in Ohio with the exception of Jackson, Lawrence, and Scioto counties in the southern part of the State where the limestone is generally wanting and the clay with its accompanying coal are only locally developed. In these counties the Lower Mercer ore, which normally lies close above the Lower Mercer limestone in localities where both members are present, is used as the base of this shale series. Likewise the Upper Mercer ore, lying close above the Upper Mercer limestone and therefore near the Bedford coal, marks the upper limit.

In some localities the shales between the Lower Mercer limestone horizon and the Bedford clay are separated by a coal into two beds of about equal thickness. As this coal bed is of local importance in Scioto, Lawrence, and Jackson counties only, where it is known as the Webster Block coal, and as the coal or its accompanying clay is rather patchy in distribution elsewhere on the outcrop, thus rendering the separation of the overlying and underlying shales somewhat arbitrary, the Middle Mercer and Lower Mercer shales are considered together in this discussion. The combined thickness of Middle and Upper Mercer shales in Ohio averages about 25 feet. Outcrops are present in Scioto, Lawrence, Jackson, Vinton, Hocking, Perry, Muskingum, Coshocton, Holmes, Tuscarawas, Wayne, Stark, Summit, Portage, Mahoning, and Columbiana counties. As these shales have not been utilized in Ohio to any great extent for ceramic purposes, their occurrence and character will be traced only in a general way.

In Scioto County the Middle and Upper Mercer shales outcrop in Green, Vernon, and Bloom townships, where their combined thickness averages about 52 feet. In general these beds have their greatest thickness in Green Township at the southern end of the belt of outcrops, from where they gradually thin to the northward through Scioto, Lawrence, and Jackson counties into Vinton County. Near Ohio Furnace in the southern part of Green Township the Middle and Upper Mercer horizons consist of sandstone and shale with an aggregate thickness of about 105 feet. In Section 28, Vernon Township, the succession is as follows:[1]

	Ft.	In.
Coal, *Tionesta*	1	0
Shale and covered	32	0
Ore, *Upper Mercer*	..	4
Shale and covered, *Upper Mercer*	22	0
Coal blossom, *Upper Mercer*	1	0
Sandstone and covered, *Middle Mercer*	19	0
Ore, *Lower Mercer*	..	3

The Upper and Lower Mercer limestones are wanting at this locality but the ores which lie above these beds are well represented.

On the land of the Webster Brick Company in Section 24, Bloom Township, the Middle and Upper Mercer horizons consist of shale and sandstone of about equal proportions with an aggregate thickness of about 59 feet. The shales have not been utilized in Scioto County.

[1] Geol. Survey Ohio, 4th Ser., Bull. 20, p. 571, 1916.

The Middle and Upper Mercer shales are exposed along the western edge of Lawrence County in Hamilton, Elizabeth, Decatur, and Washington townships. The combined thickness of these beds averages about 55 feet for the county. The Middle Mercer, which comprises about the lower one-half, is composed chiefly of shale, but the Upper Mercer consists of both shale and sandstone. The Lower Mercer shale is a possible source for brick materials in Lawrence County, but it has not been utilized for that purpose.

In Jackson County both shale and sandstone are present on the Middle and Upper Mercer horizons. Where shale is present in good thickness it is an asset to the county as the material is suitable for ceramic purposes. Outcrops of these horizons are found in Hamilton, Jefferson, Scioto, Franklin, Bloomfield, Lick, Coal, Washington, and Milton townships. The thickness of the Middle and Upper Mercer horizons varies from 40 to 60 feet but averages 50 feet. The general relations are illustrated by the following record from Section 13, Washington Township:[1]

		Ft.	In.
Sandstone		11	0
Ore and flinty limestone, *Upper Mercer*		..	4
Shale		4	0
Shale with thin ore layers		3	0
Coal blossom		..	8
Clay, light		1	4
Shale, sandy		4	10
Ore, kidney		..	2
Sandstone, shaly		11	0
Shale and covered		8	0
Shale clay, light and pink		6	0
Shale and covered		6	6
Ore	*Lower Mercer*	..	3
Shale	*Lower Mercer*	1	0
Ore	*Lower Mercer*	..	10
Shale, fossiliferous		1	6
Shale		2	1
Limestone, *Lower Mercer*		0	10

The Upper Mercer coal, which is generally present in Jackson County about midway between the Lower and Upper Mercer limestones, is not represented in the above section.

The Middle and Upper Mercer shales outcrop over a large area in Vinton County which includes western Clinton, Elk, eastern Richland, eastern Jackson, Swan, and western Brown townships. Along the western edge of the belt of outcrops the beds are present near the summits of the ridges and hilltops, but due to the dip they are near drainage level along its eastern margin. Both shale and sandstone are represented. The

[1] Geol. Survey Ohio, 4th Ser., Bull. 20, p. 148, 1916.

thickness is quite variable but averages about 40 feet. The following measurements from Section 11, Richland Township, are typical:[1]

		Ft.	In.
Coal blossom, *Bedford*		..	6
Clay, siliceous, plastic		1	6
Sandstone, shaly	*Upper Mercer*	11	6
Shale, dark, very siliceous	*Upper Mercer*	1	6
Coal blossom, *Upper Mercer*		1	0
Clay, shale and covered	*Middle Mercer*	4	0
Shale, parts covered	*Middle Mercer*	8	8
Ore, blocky	*Middle Mercer*	..	2
Shale, gray, siliceous	*Middle Mercer*	2	4
Limestone, blue, shaly, fossiliferous	*Lower Mercer*	4	10
Limestone, blue, hard, fossiliferous	*Lower Mercer*	..	8

From northern Vinton County the outcrops of the Middle and Upper Mercer shale horizons extend into Hocking County where they occur in Washington, Starr, Green, and Falls Gore townships. The base of these shales is well defined as the Lower Mercer limestone is generally present in good development throughout the county, but the Bedford clay and coal which mark the top of this series are wanting over large areas as is also the overlying Upper Mercer limestone. At Greendale in Green Township the Middle and Upper Mercer horizons are composed entirely of shale with a total thickness of about 26 feet. A description of the exposures on Monkey Run in Section 17, Green Township, is given below:

		Ft.	In.
Flint, one block	*Upper Mercer*	1	2
Flint, one block	*Upper Mercer*	..	10
Shale and covered		14	0
Limestone, bluish, hard	*Lower Mercer*	..	4
Shale, blue, fossiliferous	*Lower Mercer*	..	4
Limestone, blue, fossiliferous	*Lower Mercer*	..	2
Shale, black		1	2
Coal	*Middle Mercer*	..	6
Shale, black, with thin coal bands	*Middle Mercer*	..	8
Coal, bony	*Middle Mercer*	..	2
Clay, light, plastic		3	0

The Mercer shale is well developed throughout Starr Township, as is also the case in eastern Washington Township. At the south edge of Union Furnace the shales overlying the Lower Mercer limestone are exposed in a railroad cut where they have the following measurements:

	Ft.	In.
Shale, gray	3	0
Shale, black	..	10
Clay	1	0
Covered	2	3
Shale, gray, sandy	13	6
Covered interval	21	0
Limestone, *Lower Mercer*	..	..

[1] Geol. Survey Ohio, 4th Ser., Bull. 31, p. 128, 1927.

On June 16, 1929, a sample was cut from the 13-foot 6-inch bed of shale exposed at this locality and was submitted for chemical analysis and physical tests. The results are as follows:

Sample No. 20

Tests of Upper Mercer shale near Union Furnace, Hocking County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.55
Water, combined, H_2O+	5.09
Silica, SiO_2	59.90
Alumina, Al_2O_3	18.29
Titanic oxide, TiO_2	0.99
Phosphorus pentoxide, P_2O_5	0.18
Ferric oxide, Fe_2O_3	7.34
Ferrous oxide, FeO	1.25
Lime, CaO	0.27
Magnesia, MgO	1.40
Sodium oxide, Na_2O	0.41
Potassium oxide, K_2O	2.27
Manganese oxide, MnO	0.16
Sulphur, S	0.04
Carbon dioxide, CO_2	0.43
Carbon, organic, C	0.55

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .124 \\ Na_2O & .022 \\ CaO & .015 \\ MgO & .076 \\ FeO & .430 \\ MnO & .009 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.275 \\ TiO_2 & 0.054 \\ P_2O_5 & 0.009 \end{array}\right.$$

$$RO \quad .676$$

Physical properties, determined by Chester R. Austin
Properties in green state

Workability: This material is rather short. A badly featheredged column is extruded from the die.

Time of slaking: 47.66 minutes.

Water of plasticity: 21.64 per cent.

Dry shrinkage:

Volume: 11.52 per cent.

Linear: 3.70 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 235 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	27.43	8.94	2.9	14.42	1.90	2.63
04	23.20	13.88	4.4	11.43	2.10	2.63
02	21.05	17.17	5.4	10.04	2.13	2.65
1	18.21	21.08	6.6	8.32	2.20	2.68
3	14.07	24.03	7.4	8.40	2.28	2.66
5	9.32	25.40	7.8	3.99	2.34	2.57
7	3.21	26.51	8.1	1.37	2.34	2.42

Fired modulus of rupture:
Cone 02, 2,156 pounds per square inch.
Cone 5, 3,426 pounds per square inch.
Fired specific impact strength:
Cone 03, 1.42 centimeter kilograms per square centimeter.
Cone 4, 1.49 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 5, 13,622 pounds per square inch.
Best firing range: Cone 06 to cone 7.
Overfiring temperature: Cone 7.
Pyrometric cone equivalent: Cone 10-11.

Scumming: Scum occurs on all trials fired to cone 2 and lower but scum is not apparent on trials fired above cone 2. One pound of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: A good salt glaze having a reddish brown color with some grayish-green mottle is produced at 2,100°F. The glaze produced at 2,050°F. is very dead looking with many pimples. When $BaCO_3$ is added a glaze is not produced at 2,100°F.

Utilization: This shale was not being utilized for ceramic purposes. Its various properties adapt it to the production of paving brick, face brick, and common brick. The fired material has a stony structure. A good red color is produced at cone 01.

The Middle and Upper Mercer shales are present through central Perry County where outcrops are found in Monday Creek, western Salt Lick, Jackson, northwestern Pike, Reading, and Clayton townships. Although at a few places local deposits of sandstone are present the chief material on these horizons is sandy shale. The thickness varies from 20 to 32 feet. The Upper Mercer coal and clay which normally occur about the middle of these beds is wanting over large areas in this county. The general relations are illustrated by the following measurements secured by Wilber Stout from Section 17, Salt Lick Township, where Lower Mercer limestone is found near drainage level:

		Ft.	In.
Shale, weathered, fossiliferous, *Putnam Hill* horizon		..	4
Coal, good	*Brookville*	..	8
Shale	*Brookville*	..	1½
Coal	*Brookville*	..	3½
Clay and covered		3	0
Sandstone and covered		10	9
Flint, black	*Upper Mercer*	..	11
Limestone, irregular	*Upper Mercer*	1	3
Sandstone, hard		1	0
Shale, dark and covered		1	3
Coal, bony, *Bedford*		..	4
Shale and shaly sandstone		29	7
Limestone, *Lower Mercer*		..	6

The Junction City Sewer Pipe Company at Junction City, in Jackson Township, is now using Mercer shale for the manufacture of sewer pipe. The rock exposures in the pit are described below:

	Ft.	In.
Shale, siliceous, micaceous	3	0
Shale, siliceous, ferruginous	1	0
Sandstone, argillaceous, ferruginous	..	4
Clay, gray, siliceous	..	10
Coal, *Upper Mercer, No. 3a*	..	4
Clay, gray, siliceous	1	8
Iron ore, nodular	1	3
Shale, siliceous, carbonaceous	..	6
Clay, brown, ferruginous	1	0
Clay, dark, carbonaceous	1	0
Clay, gray, short, ferruginous	6	9
Shale, gray, sandy	5	2
Bottom of pit	..	..
Shale, gray, sandy	8	0
Shale, dark, carbonaceous, fossiliferous, *Lower Mercer* horizon	2	6

Both the clay and shale exposed in the pit are utilized at the plant but the iron ore is discarded so far as possible. A sample of the beds utilized was secured on June 19, 1929, and was submitted for chemical analysis and physical tests. The results are stated below:

Sample No. 17

Tests of Middle and Upper Mercer shales from pit of the Junction City Sewer Pipe Company, Junction City, Perry County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.60
Water, combined, H_2O+	5.72
Silica, SiO_2	64.16
Alumina, Al_2O_3	17.95
Titanic oxide, TiO_2	0.99
Phosphorus pentoxide, P_2O_5	0.06
Ferric oxide, Fe_2O_3	5.36
Ferrous oxide, FeO	0.33
Lime, CaO	0.22
Magnesia, MgO	0.97
Sodium oxide, Na_2O	0.21
Potassium oxide, K_2O	1.97
Manganese oxide, MnO	0.04
Sulphur trioxide, SO_3	0.06
Carbon dioxide, CO_2	0.10
Carbon, organic, C	0.36

Oxide ratio

K_2O	.110				
Na_2O	.012			SiO_2	3.574
CaO	.012	Al_2O_3	1.00	TiO_2	0.055
MgO	.054			P_2O_5	0.003
FeO	.287				
MnO	.003				
RO	.478				

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has good plasticity. A good column is extruded from the die.

Time of slaking: 22.76 minutes.

Water of plasticity: 20.62 per cent.

Dry shrinkage:

Volume: 9.97 per cent.

Linear: 3.22 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 378 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	28.92	6.38	2.1	15.37	1.88	2.64
04	23.55	8.48	2.8	12.07	1.95	2.55
02	23.04	11.83	3.8	11.42	2.00	2.59
1	22.12	13.55	4.3	10.77	2.03	2.61
3	20.78	13.64	4.3	10.14	2.04	2.58
5	16.10	15.12	4.8	7.53	2.11	2.51
7	15.28	17.16	5.4	6.74	2.14	2.53
8	14.87	18.18	5.7	6.94	2.15	2.53

Fired modulus of rupture:

Cone 1, 2,031 pounds per square inch.

Cone 7, 2,579 pounds per square inch.

Fired specific impact strength:

Cone 2, 0.902 centimeter kilograms per square centimeter.

Cone 7, 1.25 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 7, 10,567 pounds per square inch.

Best firing range: Cone 06 to cone 8.

Overfiring temperature: Not determined.

Pyrometric cone equivalent: Cone 16.

Scumming: A slight scum occurs on all trials fired to cone 3 and lower. One pound of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: A good salt glaze is produced at 2,100°F. The color is a gray with many greenish stains grading into a solid brown. At 2,050°F. a good glaze is also produced, the color of which is brown and light gray with brown predominating. Some pimples are apparent in the glaze. When $BaCO_3$ is added the glaze produced at 2,100°F. has a dark tan color.

Utilization: This material was being used for the production of sewer pipe. Other probable uses include hollow tile and drain tile. The color of the body at all cones within the firing range is tan, the higher the temperature the darker the shade.

The Middle and Upper Mercer shales outcrop across the west central part of Muskingum County including part or all of Newton, Springfield, Hopewell, Falls, Muskingum, Cass, Madison, and Adams townships. Local deposits of sandstone occur as in parts of Cass and Falls townships, but the horizon is composed chiefly of sandy shale. It probably has its least thickness in Falls Township, where in some localities the interval from the Lower Mercer limestone to the Bedford clay is as little as 7 feet. The average thickness for the county is about 12 feet. The following measurements from the southern part of Section 11 are representative:[1]

[1] Geol. Survey Ohio, 4th Ser., Bull. 21, p. 84, 1918.

	Ft.	In.
Flint, black, *Upper Mercer*		8
Coal blossom, *Bedford*	1	0
Clay, part siliceous	6	0
Shale, siliceous	10	0
Shale and covered	10	6
Shale, dark	4	0
Limestone, *Lower Mercer*	1	6
Clay shale	..	2
Coal, bony, *Middle Mercer*	..	4
Clay	4	6

Shales on the Middle and Upper Mercer horizons have not been utilized in Muskingum County for the production of ceramic ware.

The Middle and Upper Mercer shale horizons are of wide extent in Coshocton County for they are above drainage in practically every township with the possible exception of Linton. The thickness varies from about 20 to 30 feet. The top of the horizon is marked by the Bedford coal which ranges in thickness from 2 to 7 feet. Mercer shales have not been utilized in this county.

In Holmes County the Middle and Upper Mercer shales are due to outcrop in Richland, Killbuck, Mechanic, Berlin, Hardy, Monroe, Paint, Salt Creek, and Prairie townships. In the western part of the belt of exposures these horizons are found near the hilltops, but due to the dip of the rocks they occur near drainage level along the eastern margin. The following section at Wayne Hill in Prairie Township illustrates the stratigraphic succession:[1]

	Ft.	In.
Coal, *Tionesta, No. 3b*	3	0
Clay	5	0
Shales	22	0
Limestone, blue, *Upper Mercer*	5	0
Coal, *Bedford*	3	6
Clay	2	0
Shales, *Middle* and *Upper Mercer*	19	6
Limestone, blue, *Lower Mercer*	3	0
Coal	2	0
Clay	3	0

In Wayne County the Middle and Upper Mercer shales are due to outcrop in Sugar Creek, Paint, Salt Creek, and Franklin townships, but as this region is drift covered very few exposures occur. The interval between the Lower and Upper Mercer limestones varies from about 20 to 25 feet, a part of which is made up of sandstone.

The Middle and Upper Mercer horizons are due above drainage in the northwestern part of Tuscarawas County including Wayne, Franklin,

[1] Geol. Survey Ohio, Vol. 5, p. 838, 1884.

Lawrence, Sandy, Sugar Creek, and northern Fairfield townships, and in the southwestern corner in Oxford, Salem, and Bucks townships. These horizons are composed chiefly of shale which varies in thickness from about 25 to 35 feet. Shales from the Middle and Upper Mercer horizons have not been utilized for the production of ceramic products in Tuscarawas County.

The Middle and Upper Mercer shales lie at or near the surface in the western half of Stark County but the glacial drift permits few exposures. In the southern part of the county these horizons are above drainage along Sugar Creek in Sugar Creek Township, along the Tuscarawas Valley in Bethlehem Township, and along Nimishillen Creek in Pike and southern Canton townships. The material is chiefly a sandy shale, which has not been utilized in a commercial way.

North and east of Stark County the Middle and Upper Mercer shales are due near the surface over a large area including southeastern Summit, southern Portage, and the northern half of Mahoning counties, but the drift is of such a thickness that few exposures occur except along the larger streams. Although the shales in this area are a potential source for materials for brick and tile production, they have never been tested for that purpose.

Tionesta and Homewood Shales

In Ohio the normal succession of the Pottsville series above the Bedford coal in ascending order is Upper Mercer limestone, Tionesta shale and sandstone, Tionesta clay and coal, Homewood sandstone and shale, and Brookville clay. As the Homewood member has not been worked in this State for shale products and as the Tionesta shale is utilized to any extent at one locality only, namely near Sugar Creek, Tuscarawas County, these two shale members will be considered together in this discussion.

The Tionesta and Homewood members are widely distributed in this State for the outcrop areas extend from the Ohio River on the south to the Pennsylvania line on the east and include parts of Scioto, Lawrence, Jackson, Vinton, Hocking, Perry, Licking, Muskingum, Coshocton, Holmes, Tuscarawas, Wayne, Stark, Portage, Columbiana, and Mahoning counties. The base of these shale members is defined by the Upper Mercer limestone horizon which is marked by limestone in the northern part, by limestone or flint in the central part, and by an iron ore bed in the southern part of the belt of outcrops.

The top of the Homewood member is defined by the Brookville clay which is rather persistent in this State although wanting over some small areas, where it is replaced by sandstone. The Tionesta and Homewood shale members are separated by the Tionesta clay which on an average lies somewhat closer to the Brookville clay than to the Upper Mercer limestone. The Tionesta coal is of only local economic importance, as it is generally too thin and too impure for profitable mining. The combined thickness of the Tionesta and Homewood members in this State averages about 40 feet. The character and stratigraphy of the deposits will be traced by counties.

Scioto County. In Scioto County the Tionesta and Homewood members outcrop well above drainage in eastern Green, Vernon, and Bloom townships. The combined thickness of these members averages about 35 feet. Both sandstone and shale are present, the sandstone in some localities being massive. In Section 28, Vernon Township, the Tionesta member is composed of shale with a thickness of about 32 feet. In Section 30, Bloom Township, the material is siliceous shale with a thickness of 29 feet. In some localities massive sandstone is the chief type of rock occurring between the Upper Mercer and Brookville horizons as illustrated by the following record from Section 5, Bloom Township:[1]

		Ft.	In.
Sandstone, shaly		4	0
Shale and covered		4	0
Coal blossom, *Brookville*		..	2
Clay, light, plastic	*Brookville*	3	6
Clay, light, siliceous	*Brookville*	2	0
Covered		6	6
Sandstone, massive		41	0
Shale and covered		4	6
Ore, kidney	*Upper Mercer*	..	5
Limestone, blocky	*Upper Mercer*	..	8

No attempts have been made to utilize the Tionesta or Homewood shales in Scioto County.

Lawrence County. Outcrops of Tionesta and Homewood members are present in Upper, Hamilton, Elizabeth, Decatur, and Washington townships, in the western part of Lawrence County. In this area the Tionesta and Brookville members have an average thickness of about 32 feet. The Tionesta coal is generally wanting in this county.

Jackson County. The Tionesta and Homewood members come to the surface in all or parts of Jefferson, Madison, Franklin, Bloomfield, Lick, Coal, Washington, and Milton townships, Jackson County, where their combined thickness varies from 15 to 37 feet but averages about 23 feet. The Tionesta coal and clay are generally wanting and therefore the two shale horizons can not be separated. Both the Tionesta and Homewood members in this county are composed of sandy shale with local deposits of sandstone. The stratigraphic relation and thickness of these members are illustrated in the following record from Section 15, Lick Township, where the normal succession is represented.[2]

[1] Geol. Survey Ohio, 4th Ser., Bull. 26, p. 217, 1923.
[2] Idem., p. 219.

		Ft.	In.
Sandstone		15	0
Ore, kidney, *Black Flint* horizon		..	6
Covered		15	0
Limestone, impure, very fossiliferous, *Putnam Hill*		1	0
Shale and covered		3	0
Coal blossom, *Brookville*		1	0
Clay, light, lower part siliceous		7	0
Shale	*Homewood*	4	0
Sandstone	*Homewood*	9	0
Coal blossom, *Tionesta*		1	0
Clay, siliceous		2	0
Shale, *Tionesta*		5	0
Ore, *Upper Mercer*		..	2

Vinton County. The Tionesta and Homewood members extend from Jackson County north into Vinton County where outcrops are present in Clinton, Elk, Madison, Swan, Brown, Jackson, and Richland townships. The conditions of deposition of these beds were apparently similar to those of Jackson County, as both sandstone and sandy shale are represented and as the Tionesta coal and clay are generally wanting. The sandstones, however, are usually local in their development. The thickness of the beds varies from 15 to 45 feet but the average for the county as a whole is about 24 feet. Wilber Stout secured the following record from Section 6, Elk Township, which is in general representative:

		Ft.	In.
Coal blossom, *Brookville*		1	0
Clay, siliceous	*Tionesta-Homewood*	4	0
Sandy shale and shaly sandstone	*Tionesta-Homewood*	26	0
Ore, siliceous, dark, *Upper Mercer*		..	3
Shale, dark		..	4
Coal and coaly shale, *Bedford*		..	10
Clay, impure		1	0

At the plant of the McArthur Brick Co., located at McArthur, Elk Township, sandy shale from the Homewood horizon is used to a limited extent with the Brookville clay to give color to the ware. Shale from the Tionesta-Brookville interval has not been used elsewhere in this county.

Hocking County. In Hocking County the Tionesta and Homewood shales are present above drainage in parts of Washington, Starr, Green, Ward, and Falls Gore townships. The beds are rather poorly defined as the Upper Mercer horizon is wanting over large areas, and as the Brookville clay and coal are patchy in their distribution. The Brookville clay which forms the top of the Homewood member has been used to a small extent at the plant of the Hocking Valley Products Co., now owned by the Greendale Brick Co., where the following section is found.[1]

[1] Geol. Survey Ohio, 4th Ser., Bull. 26, p. 221, 1923.

		Ft.	In.
Limestone, gray, very fossiliferous	*Putnam Hill*	..	4
Shale, blue, very fossiliferous	*Putnam Hill*	..	9
Coal, *Brookville*		..	4
Clay, light, plastic		6	0
Covered		7	2
Coal and black shale		3	0
Flint, black to gray, *Upper Mercer*		1	6
Shale, dark		1	8
Shale and coal, weathered, *Bedford*		1	0

In some localities the Homewood member disappears and the Tionesta clay coalesces with the Brookville clay. Both the sandstone and sandy shale phases of these members are represented in the outcrops in Hocking County but the shale has not been utilized for the manufacture of brick or tile.

Perry County. The Tionesta and Homewood members outcrop in parts of the following townships in Perry County: Salt Lick, Monday Creek, Jackson, Pike, Reading, Clayton, Harrison, Hopewell, and Madison. These beds are continuous across the county but show variations in thickness ranging from 10 to 44 feet. Thicknesses above the average are usually found where sandstone is present on these horizons. In Section 13, Monday Creek Township, the Tionesta and Homewood members have a combined thickness of 38 feet, most of which is sandstone. In Section 17, Salt Lick Township, the beds are composed entirely of sandstone with a total thickness of about 11 feet. The following record from Section 4, Monday Creek Township, as reported by Wilber Stout, shows the general geological succession, but the thickness of the Tionesta and Homewood members is below the average for the county.

		Ft.	In.
Shale, ferruginous, fossiliferous		..	4
Coal, *Brookville*		..	6
Clay, light, plastic		4	8
Clay shale	*Homewood*	3	0
Sandstone, irregular	*Homewood*	..	6
Shale, blue	*Homewood*	2	8
Sandstone lenses	*Homewood*	..	1
Coal	*Homewood*	..	1
Shale, gray	*Homewood*	2	4
Shale, dark	*Homewood*	1	4
Coal, *Tionesta*		1	0
Clay, plastic		3	6
Covered, *Tionesta* horizon		4	2
Flint, black	*Upper Mercer*	..	4
Limestone, blue, with large irregular masses of black flint	*Upper Mercer*	1	8

Neither the Tionesta nor Homewood member has been utilized in Perry County.

Licking County. The Tionesta and Homewood members are present near the summits of the highest elevations in Franklin and Hopewell townships, Licking County, but they are of little value.

Muskingum County. Outcrops of the Tionesta and Homewood horizons are of wide extent in Muskingum County for they are found in Newton, Brush Creek, Wayne, Springfield, Hopewell, Falls, Licking, Muskingum, Washington, Madison, Cass, and Jackson townships. The average thickness of these members is about 40 feet. In general they have about equal thickness as the Tionesta coal and clay occur near the middle of the series. Over a few small areas the Homewood member disappears and the Tionesta clay and coal lie immediately below the Brookville clay. In other localities, however, the Homewood is a massive sandstone which in places transgresses the horizons of the underlying and overlying members. Sandstone development on this horizon is found in every township in the county where exposures occur, but the extent of such areas is usually small. The general relations are illustrated by the following measurement of exposures along Beech Run a short distance north of Ellis in Muskingum Township:

		Ft.	In.
Limestone, *Putnam Hill*		4	4
Shale		..	1
Coal, *Brookville*		..	11
Clay and covered		4	6
Sandstone, shaly, gray		10	0
Shale, dark		8	0
Clay, light		2	0
Shale		3	0
Limestone and black flint, *Upper Mercer*		2	0
Shale, dark		..	8
Coal	*Bedford*	..	4
Shale, bony	*Bedford*	..	2
Coal, hard	*Bedford*	..	6
Shale and bone coal	*Bedford*	..	4
Coal, good	*Bedford*	1	6

Where the sandstone phase of the Homewood disappears there is a contraction of the interval between the Upper Mercer limestone and the Brookville clay which is usually accompanied by a thick development of the Tionesta clay. Neither the Tionesta nor Homewood shale has been utilized in this county.

Coshocton County. The horizon of the Tionesta and Homewood sha'es is above drainage in practically every township in Coshocton County. As the regional slope of the bedrocks is a little south of east, the horizon of these shale members is near the hilltops in the western part and near drainage level in the eastern part of the county. The thickness is variable for it shows a range in the southern part of the county from 15 to 50 feet. The Tionesta coal is present in some localities but it is of little value. Good exposures of the Tionesta and Homewood members occur along the Tuscarawas River Valley in Virginia and Franklin townships and along Graham Ridge in Pike and Washington townships. The following record by Wilber Stout from Section 24, Virginia Township, shows the general relations:

	Ft.	In.
Limestone, *Putnam Hill*	2	0
Covered	2	0
Coal blossom, *Brookville*	1	0
Clay shale and covered, *Homewood* horizon	17	0
Ore	..	4
Coal, *Tionesta*	1	0
Shale and covered, *Tionesta* horizon	12	8
Flint, black, *Upper Mercer*	1	0
Coal blossom, *Bedford*	1	0
Clay and covered	6	0

Holmes County. The Tionesta and Homewood shales are above drainage in every township in Holmes County. In the western part, however, the area of these members is small as they lie near the top of the hills and ridges. Their combined thickness averages between 35 and 40 feet. The Tionesta coal is generally present but it is too thin and impure for profitable mining. The Tionesta and Homewood shale members are well exposed along the Salt Creek Valley in Prairie Township. The shale immediately underlying the Brookville clay was formerly used to a small extent for the manufacture of brick at the plant of the Mount Cherry Coal Co., in Section 25. The material has not been utilized at any other place in this county.

Wayne County. In Wayne County Tionesta and Homewood shales are above drainage in Franklin, Salt Creek, Paint, and Sugar Creek townships, but due to the sheet of glacial drift at the surface very few exposures occur. The beds consist of sandstones and sandy shales with a combined thickness which varies from 30 to 50 feet. The Tionesta coal is generally present, but it is too thin for profitable mining.

Tuscarawas County. The Tionesta and Homewood members are due above drainage over a large area in the northwestern third and in the southwestern corner of Tuscarawas County. This area includes all or parts of Wayne, Sugar Creek, Auburn, Franklin, Lawrence, Sandy, Oxford, and Salem townships. The members consist chiefly of sandy shales having a combined thickness ranging from 15 to 40 feet. The Tionesta coal is generally present in this county, having a workable thickness in Sugar Creek, Wayne, Franklin, and Lawrence townships, but it is of rather low grade. At Sugar Creek in Sugar Creek Township the Tionesta shales are used extensively by the Sugar Creek Clay Products Co. for the production of face brick. The clay underlying the Brookville coal is used to produce light-colored varieties and the shales for the darker shades of red and reddish brown. The Bedford coal is utilized in part for fuel. The exposures in the pit are as follows:

		Ft.	In.
Limestone, weathered, *Putnam Hill*		..	8
Shale, weathered		..	5
Coal, *Brookville*		1	6
Clay, gray, plastic, *Brookville*		4	4
Sandstone, clay-bonded		..	10
Clay, gray, sandy, micaceous, *Tionesta*		4	4
Shale, gray, siliceous, with some iron concretions	*Tionesta*	32	0
Shale, dark	*Tionesta*	5	0
Coal	*Bedford*	..	8
Parting	*Bedford*	..	2
Coal	*Bedford*	..	3
Parting	*Bedford*	..	2
Coal	*Bedford*	2	10

The Tionesta shale, with a total thickness of 37 feet, was sampled on August 7, 1929. The sample was submitted for chemical analysis and other tests with the following results:

Sample No. 16

Tests of Tionesta shale from the pit of Sugar Creek Clay Products Company, Sugar Creek, Tuscarawas County

Downs Schaaf, analyst

Chemical analysis

Water, hydroscopic, H_2O-	1.07
Water, combined, H_2O+	5.65
Silica, SiO_2	58.25
Alumina, Al_2O_3	21.77
Titanic oxide, TiO_2	1.01
Phosphorus pentoxide, P_2O_5	0.35
Ferric oxide, Fe_2O_3	2.29
Ferrous oxide, FeO	3.28
Lime, CaO	0.42
Magnesia, MgO	1.08
Sodium oxide, Na_2O	0.05
Potassium oxide, K_2O	3.65
Manganese oxide, MnO	0.06
Sulphur, S	0.05
Carbon dioxide, CO_2	0.65
Carbon, organic, C	0.38

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .168 \\ Na_2O & .002 \\ CaO & .019 \\ MgO & .049 \\ FeO & .245 \\ MnO & .003 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 2.675 \\ TiO_2 & 0.046 \\ P_2O_5 & 0.016 \end{array}\right.$$

$$RO \quad .486$$

Physical properties, determined by Chester R. Austin
Properties in green state

Workability: This material has good plasticity. A good column is extruded from the die.

Time of slaking: 11.2 minutes.

Water of plasticity: 19.97 per cent.

Dry shrinkage:

Volume: 9.19 per cent.

Linear: 2.98 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 292 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	24.28	12.90	4.1	11.95	2.04	2.69
04	16.71	17.40	5.5	7.88	2.15	2.57
02	12.50	21.37	6.7	5.63	2.26	2.57
1	9.24	24.73	7.6	4.01	2.34	2.57
3	6.95	27.46	8.4	3.00	2.40	2.58
5	3.69	26.83	8.2	1.22	3.04	3.15
7	2.12	27.10	8.3	0.89	2.40	2.45

Fired modulus of rupture:

Cone 04, 2,869 pounds per square inch.

Cone 4, 4,257 pounds per square inch.

Fired specific impact strength:

Cone 05, 1.57 centimeter kilograms per square centimeter.

Cone 4, 1.18 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 4, 12,495 pounds per square inch.

Best firing range: Cone 06 to cone 4.

Overfiring temperature: Cone 5.

Pyrometric cone equivalent: Cone 14-15.

Scumming: Scum occurs on all trials fired to cone 3 and lower but scum is not apparent on trials fired above cone 3. One pound of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The salt glaze produced at 2,050°F. and 2,100°F. has a reddish brown color with some greenish mottling. When $BaCO_3$ is added, the glaze produced at 2,100°F. has a chocolate brown color.

Utilization: This shale was being used for the production of face brick. It can be used also for common brick. The fired material develops a good red color at cone 02.

The Tionesta shale is likewise utilized to some extent in the plants operated by Shepfer and Moomaw Bros. at Sugar Creek. In addition to the Tionesta, the Brookville clay and the shale beds above the Putnam Hill limestone are also worked for the production of face brick and building tile. The Bedford coal is mined for fuel. A section of the exposures in the pit below the Putnam Hill limestone is given below:

		Ft.	In.
Limestone, *Putnam Hill*		1	7
Shale, gray, calcareous		..	3
Black shale and shaly coal	*Brookville*	..	7
Coal	*Brookville*	..	10
Clay, bluish-gray, short, *Brookville*		12	0
Shale, greenish-gray, ferruginous, sandy		17	6
Shale, dark, carbonaceous, with ore nodules		7	0
Shale, dark, carbonaceous		3	0
Coal	*Bedford*	1	4
Shale, parting	*Bedford*	..	3
Coal	*Bedford*	2	11
Shale, black, bituminous	*Bedford*	..	3
Clay, weathered, *Tionesta*		4	6

Large bodies of shale are found on the Homewood and Tionesta horizons in other parts of Tuscarawas County but outside of the Sugar Creek district, the material has not been utilized for brick or tile.

Stark County. The Tionesta and Homewood shales lie near the surface over a large area in Stark County and, if it were not for glacial drift deposits which cover much of the area, these beds would outcrop in every township with the exception of Paris and Washington in the southeastern part. The Brookville clay which immediately overlies the Homewood shale has been worked extensively for ceramic products along the valley of Nimishillen Creek in Pike and Canton townships, and the Brookville coal is the chief local source of fuel in the county. The thickness of the Tionesta and Homewood shales in Stark County varies from 30 to 50 feet. The general relations are shown in the following record from Section 27, Pike Township:[1]

		Ft.	In.
Shale		20	0
Limestone, *Putnam Hill*		4	0
Coal, *Brookville*		1	6
Clay, plastic	*Brookville*	3	0
Clay, light, siliceous	*Brookville*	6	0
Shale, *Homewood*		18	0
Clay, *Tionesta*		8	0
Shale and sandstone, *Tionesta*		28	0
Limestone, dark, *Upper Mercer*		3	0

Homewood shale has been utilized to some extent at Plant No. 2 of the Federal Clay Products Co. located in Section 27, Pike Township, but the chief source of material is the Tionesta clay. A measurement of the exposures in the pit follows:

	Ft.	In.
Limestone, *Putnam Hill*	2	0
Coal, *Brookville*	1	6
Clay, gray, short, *Brookville*	6	0

[1] Geol. Survey Ohio, 4th Ser., Bull. 26, p. 236, 1923.

	Ft.	In.
Shale, a little sandy, *Homewood*	14	6
Smut, streak, *Tionesta*	..	1
Clay, dark, plastic (*Tionesta*)	3	4
Clay, gray (*Tionesta*)	5	0

The Homewood shale is stripped by steam shovel and the clay loaded from the open cut. A sample of the shale was cut on September 11, 1929, and was submitted for chemical analysis and other tests. The results are given below:

Sample No. 15

Tests of Homewood shale from pit of the Federal Clay Products Company, East Sparta, Stark County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.68
Water, combined, H_2O+	5.05
Silica, SiO_2	61.25
Alumina, Al_2O_3	16.31
Titanic oxide, TiO_2	1.10
Phosphorus pentoxide, P_2O_5	0.25
Ferric oxide, Fe_2O_3	7.22
Ferrous oxide, FeO	1.02
Lime, CaO	0.70
Magnesia, MgO	1.55
Sodium oxide, Na_2O	0.32
Potassium oxide, K_2O	3.20
Manganese oxide, MnO	0.07
Sulphur, S	0.03
Carbon dioxide, CO_2	0.33
Carbon, organic, C	0.18

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .196 \\ Na_2O & .020 \\ CaO & .043 \\ MgO & .095 \\ FeO & .461 \\ MnO & .004 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.755 \\ TiO_2 & 0.068 \\ P_2O_5 & 0.015 \end{array}\right.$$

$$RO \quad .819$$

Physical properties, determined by Chester R. Austin
Properties in green state

Workability: This material has rather short plasticity. A featheredged column is extruded from the die.

Time of slaking: 12.51 minutes.

Water of plasticity: 19.51 per cent.

Dry shrinkage:

Volume: 9.81 per cent.

Linear: 3.17 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 193 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	23.21	9.14	2.9	11.83	2.00	2.57
04	17.54	13.70	4.4	8.46	2.07	2.51
02	15.97	16.29	5.2	7.50	2.13	2.54
1	14.11	19.06	6.0	6.40	2.21	2.57
3	12.76	21.23	6.6	5.02	2.26	2.56
5	12.21	22.60	7.0	3.51	2.27	2.47
7	3.90	23.18	7.2	1.68	2.32	2.41

Fired modulus of rupture:
Cone 02, 2,103 pounds per square inch.
Cone 5, 3,521 pounds per square inch.
Fired specific impact strength:
Cone 03, 1.55 centimeter kilograms per square centimeter.
Cone 4, 1.33 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 5, 12,992 pounds per square inch.
Best firing range: Cone 06 to cone 7.
Overfiring temperature: Cone 9.
Pyrometric cone equivalent: Cone 14-15.

Scumming: Scum occurs on all trials fired to cone 5 and lower but scum is not apparent on trials fired above cone 5. Two pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The salt glaze developed at 2,100° F. is a dark yellowish green on a pinkish-gray colored background. The glaze produced at 2,050° F. has a dark greenish-brown color. When $BaCO_3$ is added the glaze produced at 2,100°F. has a brown color.

Utilization: This shale was being used for the production of face brick. It can be used also for the manufacture of common brick. The fired material develops a good red color at cone 1.

Good bodies of shale are found on the Tionesta and Homewood horizons along Nimishillen Valley north of East Sparta in Pike and Canton townships, but the material was not utilized. At Howenstein these members have a thickness of about 49 feet and are composed almost entirely of shale. At North Industry the material is a sandy shale. Near Greentown in Lake Township the Brookville clay was mined for a number of years and utilized for ceramic purposes. The following section from this locality shows the Tionesta coal and Upper Mercer limestone horizons with the Tionesta and Homewood shales wanting:[1]

	Ft.	In.
Limestone, *Putnam Hill*	5	0
Coal, *Brookville*	6	0
Clay, *Brookville*	8	0
Coal, *Tionesta*	..	6
Clay, *Tionesta*	7	0
Limestone and ore, *Upper Mercer*	1	10

[1] Geol. Survey Ohio, Vol. V, p. 231, 1884.

Portage and Mahoning Counties. The horizons of the Tionesta and Homewood shales are due at the surface through the southern part of Portage and the central part of Mahoning counties, but owing to deposits of glacial drift few exposures occur and therefore little is known about the character of the deposits.

Columbiana County. In Columbiana County the Tionesta-Homewood shale horizons are exposed near drainage level along the Little Beaver River in Saint Clair Township and along the Ohio River Valley from the Pennsylvania state line west to East Liverpool. The horizons are represented by shale and shaly sandstone which have largely replaced the Brookville coal and clay. The following section secured near the mouth of Bieler Run in Saint Clair Township shows the general character and succession of the beds.

		Ft.	In.
Shale, black, fossiliferous	*Clarion* horizon	1	4
Shale, gray, siliceous	*Clarion* horizon	8	2
Ore, nodular, fossiliferous	*Clarion* horizon	..	2
Shale and shaly sandstone		8	2
Clay, plastic, siliceous, *Clarion*		6	0
Sandstone, thin-bedded to shaly, *Homewood* in part		28	6
Clay shale, dark, with thin layers of shaly coal, *Tionesta*		..	8
Sandstone, hard, blue	*Tionesta*	..	11
Shale, with parts covered	*Tionesta*	14	0
Limestone, ferruginous, fossiliferous	*Upper Mercer*	..	5
Shale, calcareous, very fossiliferous	*Upper Mercer*	..	2
Clay shale		3	0
Shale		10	0

Neither Tionesta nor Homewood shale has been utilized in Columbiana County.

ALLEGHENY SERIES

The Allegheny is the richest in natural resources of all the coal-bearing series of Ohio. It contains valuable coal beds of workable thickness and broad extent; some of its clays are of high quality and inexhaustible in supply, and certain shale beds are widely used as sources of material for the production of brick and tile. The limestones are generally thin and relatively unimportant, although at a few localities they are quarried for industrial purposes. The thickness of the Allegheny series varies from place to place. The maximum is about 250 feet and the minimum about 175 with an average of about 212 feet for the State as a whole. Stratigraphically, the series begins at the top of the Pottsville, which is the base of the Brookville or No. 4 coal, and extends upward to the top of the Upper Freeport or No. 7 coal. The succession of members in the Allegheny series together with the general character and average thickness of each in Ohio are shown in this general section:

General Section of the Allegheny Series of Ohio[1]

Series	Member	General description	Thickness Ft.	In.
Allegheny	Upper Freeport, No. 7....	Coal, patchy....................	3	0
		Clay and shale.................	7	0
	Upper Freeport...........	Limestone and marly shale.......	2	0
	Bolivar	Coal, local, thin..............	..	3
		Clay, flint and plastic........	5	0
	Upper Freeport...........	Shale and sandstone............	33	0
	Lower Freeport or Rogers, No. 6a................	Coal, patchy....................	1	0
		Clay, impure....................	2	6
	Lower Freeport...........	Limestone	1	0
	Lower Freeport...........	Shale and sandstone............	36	0
	Washingtonville	Shale, carbonaceous.............	4	0
	Middle Kittanning, No. 6..	Coal, persistent................	4	0
		Clay, siliceous.................	3	6
	Salem	Limestone, impure, local........	..	6
	Strasburg	Shale, siliceous, with kidney ore..	10	0
	Strasburg	Coal, local.....................	..	6
	Oak Hill.................	Clay, flint and plastic.........	4	0
		Shales, siliceous...............	3	0
	Hamden	Limestone, unsteady, marine.....	4	0
	Lower Kittanning, No. 5..	Coal	2	4
		Clay, plastic...................	5	0
	Lawrence	Coal, shaly, local..............	..	4
		Clay, flint and plastic.........	6	0
	Lower Kittanning.........	Shale and sandstone.............	8	2
	Ferriferous	Ore, irregular..................	..	8
	Vanport	Limestone, marine...............	6	0
		Shale, carbonaceous.............	5	6
	Clarion, No. 4a..........	Coal, patchy....................	4	0
		Clay, flint and plastic.........	5	0
	Clarion	Shale and sandstone.............	38	6
	Putnam Hill..............	Limestone, marine...............	4	0
	Brookville, No. 4.........	Coal, steady....................	2	0

In previous reports of this Survey involving the stratigraphy of the Pennsylvanian rocks of Ohio, names have been used consistently for the various coal, clay, limestone, iron ore, and sandstone beds, but little attention has been paid to the shale intervals as they are of no value for purposes of correlation. For the sake of convenience in description the shale beds discussed in this report are given the name of the first prominent underlying coal, except where a prominent sandstone is found on the same horizon as the shale bed. In the latter case the name of the sandstone is applied.

The Allegheny series outcrops over an area of about 2,200 square miles in Ohio. This area occurs as an elongated belt extending across the eastern part of the State from the Ohio River on the south to the Pennsylvania line on the east and including part or all of Lawrence, Scioto, Jackson, Gallia, Vinton, Hocking, Athens, Perry, Muskingum,

[1] Geol. Survey Ohio, 4th Ser., Bull. 34, opposite p. 6, 1929.

Coshocton, Guernsey, Holmes, Tuscarawas, Harrison, Carroll, Stark, Wayne, Portage, Mahoning, Columbiana, and Jefferson counties. The distribution, thickness, and character of the various shale members of this series are described in the following pages.

Clarion Shale

The Clarion is the lowest shale and sandstone member of the Allegheny series. Stratigraphically, it lies immediately above the Putnam Hill limestone from which it extends upward to the base of the Clarion clay. Sandstone is of common occurrence on this horizon although in places the sandstone becomes massive and occupies the entire interval or even transgresses on the horizons of the underlying and overlying members. In northern Jackson and Vinton counties two coals and a flint bed, which in ascending order are known as the Ogan coal, Zaleski flint, and Winters coal, come into the section about midway between the Putnam Hill limestone and the Clarion clay. These beds are of local importance only, as they are generally wanting elsewhere in the State. The base of the Clarion shale is clearly defined as the Putnam Hill limestone is generally present except at the northeastern and southern parts of the belt of outcrops. The top of the member in some localities is not definitely marked as the Clarion clay and its overlying coal are patchy in distribution, as the Vanport limestone is often wanting and as the Ferriferous ore is likewise irregular in its occurrence. The Clarion shale horizon is above drainage in parts or all of Scioto, Lawrence, Jackson, Vinton, Hocking, Perry, Licking, Muskingum, Coshocton, Holmes, Wayne, Tuscarawas, Stark, Portage, Mahoning, and Columbiana counties. Shale on this horizon has been utilized for the production of brick or tile in Vinton, Perry, Muskingum, Tuscarawas, and Stark counties. The distribution, character, and thickness of the bed are discussed in the following pages by counties.

Scioto County. The Clarion member is found near the crest of the high knobs and ridges in Green, Vernon, and Porter townships in eastern Scioto County, but the areal extent of the deposits is small. Both sandstone and shale are represented, the sandstone in many places approaching a ganister in character. The average thickness of the Clarion sandstone and shale member in Scioto County is about 65 feet.

Lawrence County. In Lawrence County the Clarion shale horizon is above drainage in parts of Perry, Upper, Hamilton, Elizabeth, Decatur, Washington, and Symmes townships. The average thickness of the member is about 60 feet. The beds show a great variation in character, ranging from soft fine-grained to highly siliceous shales and massive sandstone. Some of these varieties are suitable for the production of brick. At Center Furnace in Elizabeth Township the Clarion beds consist of shale with a thickness of 68 feet. In Section 34, Washington Township, the thickness is 56 feet, the upper 25 feet of which is sandstone. At Lawrence Furnace in Elizabeth Township, the sequence of beds is as follows:[1]

	Ft.	In.
Limestone, *Ferriferous*	7	0
Coal blossom, *Clarion*	..	2
Clay, good, plastic	8	0
Shale and shaly sandstone	17	0
Coal blossom	..	6
Shale	3	0
Coal blossom	..	2
Clay shale	3	0
Sandstone	1	0
Shale	14	0
Sandstone, shaly	8	0
Shale	9	0
Coal, *Brookville*	1	0
Clay	3	6

The Middle Kittanning coal is well developed in this county and the Clarion coal is of minable thickness in Decatur and Washington townships.

Gallia County. The Clarion horizon is due above drainage over small areas in Greenfield and Huntington townships, Gallia County. In these areas the member is composed chiefly of massive sandstone.

Jackson County. In Jackson County the Clarion horizon outcrops in Jefferson, Madison, Franklin, Bloomfield, Lick, Coal, Washington, and Milton townships; it is composed of sandstone and shale, and has an average thickness in the county of about 50 feet. In the northern part the Clarion horizon is divided into two parts by the Winters coal and underlying Zaleski flint. Sandstone predominates on the Clarion horizon above the Winters coal while below the Zaleski flint the beds consist of both sandstone and siliceous shale. The following record secured by Wilber Stout is from Section 33, Milton Township:

	Ft.	In.
Coal blossom, *Clarion*	4	0
Clay, sandy	5	0
Sandstone, shaly	10	0
Covered	4	6
Coal blossom, *Winters*	..	6
Clay, light	7	0
Sandstone	5	0
Covered	6	0
Shale, sandy	7	0
Ore nodules in shale	..	4
Shale	..	8
Coal, shaly, *Brookville*	..	6
Clay, light, plastic	2	0

[1] Geol. Survey Ohio, 4th Ser., Bull. 20, p. 306, 1916.

In Section 35, Lick Township, the Clarion has a thickness of about 49 feet. Sandstone is present above the Zaleski flint horizon and sandy shale makes up the beds below. In Section 25, Jefferson Township, the Clarion member is composed almost entirely of sandstone with a thickness of about 50 feet. The Clarion coal is of minable thickness over large areas in Jackson County.

Vinton County. From Jackson County the belt of outcrops of the Clarion member extends to the north and northeast into Vinton County where exposures are due in Wilkesville, Vinton, Clinton, Richland, Jackson, Elk, Madison, Swan, and Brown townships. Along the western edge of the outcrop belt in Jackson and Richland townships the beds composing this member lie near the crests of the highest hills and ridges, but in the eastern part of the county the exposures are near drainage level along the major streams. The average thickness of the beds in Vinton County is about 42 feet.

The Clarion shale and sandstone are divided into two parts in Vinton County by local members which in descending order are Winters coal and clay, Zaleski flint, and Ogan coal. The following record from Section 12, Elk Township, shows the general relations:[1]

		Ft.	In.
Coal blossom, *Clarion*		2	0
Clay and covered		6	0
Shale, gray, with ore nodules, *Clarion*		17	0
Coal, weathered, *Winters*		2	3
Clay and covered		3	0
Flint, gray to dark, *Zaleski*		2	4
Coal, weathered, *Ogan*		..	10
Clay and covered		4	4
Shale, gray	*Clarion*	2	0
Ore, irregular, local	*Clarion*	..	4
Shale, gray	*Clarion*	11	8
Shale, dark blue, fossiliferous, *Putnam Hill*		1	0
Coal and partings, weathered, *Brookville*		2	3

Of these local members (Ogan coal, Zaleski flint, and Winters coal), the Winters coal is the most important as it is the most persistent in this county and as it is a local source of fuel in Elk, western Madison, western Vinton, and eastern Clinton townships. In Swan Township the Ogan, Zaleski, and Winters members disappear and the Clarion shale and sandstone thin to such an extent that the Clarion clay and coal lie only a very few feet above the Putnam Hill limestone horizon.

The Clarion shales are utilized at only one locality in Vinton County, namely at the plant of the McArthur Brick Co., located near McArthur in Section 28, Elk Township. Face brick is the chief product of this plant. In addition to the Clarion shale, the Winters clay, Brookville clay,

[1] Geol. Survey Ohio, 4th Ser., Bull. 31, p. 183, 1927.

and Homewood shale are also used to produce desired types or colors of ware. A composite section of exposures in the pit follows:

	Ft.	In.
Shale, sandy and plate-like	6	0
Shale, dark	4	6
Shale, dark	2	0
Coal, *Winters*	..	9
Clay, bluish gray, siliceous, *Winters*	3	6
Shale, bluish gray, sandy, *Clarion*	23	9
Shale, gray, calcareous, fossiliferous, *Putnam Hill* horizon	4	0
Shale, black, with thin coal bands } *Brookville*	..	2
Coal } *Brookville*	1	6
Clay, siliceous, *Brookville*	4	8
Shale, micaceous, sandy, *Homewood*	5	8

The 23-foot-9-inch bed of Clarion shale overlying the Putnam Hill horizon was sampled on June 17, 1929, and the sample was submitted for testing. The results are as follows:

Sample No. 34

Tests of Clarion shale from pit of the McArthur Brick Company, McArthur, Vinton County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.19
Water, combined, H_2O+	5.54
Silica, SiO_2	57.50
Alumina, Al_2O_3	18.01
Titanic oxide, TiO_2	0.99
Phosphorus pentoxide, P_2O_5	0.08
Ferric oxide, Fe_2O_3	5.02
Ferrous oxide, FeO	4.12
Lime, CaO	0.28
Magnesia, MgO	1.80
Sodium oxide, Na_2O	0.34
Potassium oxide, K_2O	3.04
Manganese oxide, MnO	0.06
Sulphur trioxide, SO_3	0.16
Carbon dioxide, CO_2	1.10
Carbon, organic, C	0.79

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .169 \\ Na_2O & .019 \\ CaO & .015 \\ MgO & .100 \\ FeO & .480 \\ MnO & .003 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.193 \\ TiO_2 & 0.055 \\ P_2O_5 & 0.004 \end{array}\right.$$

$$RO \quad .786$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has short plasticity. A badly featheredged column is extruded from the die.

Time of slaking. 19.47 minutes.

Water of plasticity: 19.29 per cent.

Dry shrinkage:

Volume: 9.00 per cent.

Linear: 2.92 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 183 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	28.42	10.80	3.5	14.59	1.95	2.72
04	20.79	16.75	5.3	9.84	2.11	2.66
02	15.66	19.05	6.0	7.37	2.18	2.60
1	11.93	21.61	6.7	5.47	2.25	2.57
3	9.59	24.43	7.6	4.13	2.32	2.57
5	4.93	25.80	7.9	2.04	2.37	2.50
7	2.40	25.76	7.9	1.01	2.37	3.39

Fired modulus of rupture:

Cone 05, 2,262 pounds per square inch.

Cone 6, 3,644 pounds per square inch.

Fired specific impact strength:

Cone 05, 1.49 centimeter kilograms per square centimeter.

Cone 4, 1.43 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 5, 14,936 pounds per square inch.

Best firing range: Cone 06 to cone 5.

Overfiring temperature: Cone 7.

Pyrometric cone equivalent: Cone 14-15.

Scumming: Scum occurs on all trials fired to cone 3 and lower but scum is not apparent on trials fired above cone 3. Three pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The color of the salt glaze produced at 2,100°F. and at 2,050°F. is a reddish-brown with some brownish-green and pinkish-gray mottling. When $BaCO_3$ is added the glaze has a light brown color at 2,100°F.

Utilization: This shale was being used chiefly for the production of face brick. It can be used also for common brick. The fired material develops a good red color at cone 02.

Bodies of shale on the Clarion horizon suitable for brick manufacture are widely distributed in Vinton County as the sandstone phase of this member is rather local in its development. Where sandstone occurs it is most generally found in the interval between the Winters coal and the Clarion clay, although in some localities it extends down to the horizon of the Brookville coal. Small bodies of sandstone are common above the Winters coal in Elk, southwestern Madison, Vinton, and eastern and central Clinton townships. The material between the Ogan coal and the Putnam Hill limestone is predominantly shale in Vinton County.

Hocking County. The Clarion shale and sandstone horizon outcrops across eastern Hocking County in Washington, Starr, Green, Ward, and eastern Falls Gore townships. In this county, however, the horizon is unimportant, as it either pinches out entirely or is represented by a very few feet of sandstone and shale. The Putnam Hill limestone is generally wanting as is also the Brookville coal. At some localities the Brookville clay lies immediately below the Clarion clay.

Perry County. The Clarion shale horizon outcrops over a wide area in Perry County for exposures occur in parts of Monday Creek, Jackson, Reading, Madison, Clayton, Harrison, Pike, Salt Lick, and Coal townships. In this area both the Clarion clay and coal are generally wanting but the overlying Vanport limestone or Ferriferous ore as well as the Putnam Hill limestone which lies at the base of the Clarion shale are generally present. The Clarion shale horizon shows great variations in thickness, measurements ranging from 20 to 60 feet. In Section 19, Monday Creek Township, the total thickness is 42 feet, the upper 17 feet being composed of sandstone and the lower part of sandy shale. Much the same condition exists in Section 18, Salt Lick Township, where the Putnam Hill limestone is overlain by 31 feet of shale above which is massive sandstone. In Section 7, Pike Township, the Clarion shale is now being worked by the Ludowici-Celadon Co. and used for the manufacture of roofing tile. A section of the exposure in the pit measured by Wilber Stout is given below:

		Ft.	In.
Shale, bluish-gray	*Clarion*	30	0
Shale, blue, fossiliferous, with ore concretions	*Clarion*	8	0
Shale, hard, very fossiliferous, *Putnam Hill* horizon		..	4
Coal	*Brookville*	..	9
Shale parting	*Brookville*	..	1
Coal	*Brookville*	1	4
Clay		3	0
Flint, black, irregular, *Upper Mercer*		7	0
Coal and shale, weathered, *Bedford*		1	0
Clay and covered		5	0

The 30-foot bed of shale lying above the Putnam Hill limestone horizon is the part utilized in the plant. A sample of this shale was secured for testing by A. E. MacGee of the National Bureau of Standards. The results are as follows:

Sample No. 206

Tests of Clarion shale from the pit of the Ludowici-Celadon Company, New Lexington, Perry County. (Tests by the Bureau of Standards.)[1]

Chemical analysis		*Oxide ratio*					
Loss on ignition	6.4	K_2O	.17	Al_2O_3	1.00	SiO_2	3.44
Silica, SiO_2	60.6	Na_2O	.03			TiO_2	0.06
Alumina, Al_2O_3	17.6	CaO	.04				
Ferric oxide, Fe_2O_3	7.2	MgO	.04				
Lime, CaO	0.7	FeO	.37				
Magnesia, MgO	0.8						
Titanic oxide, TiO_2	1.0	RO	.65				
Sodium oxide, Na_2O	0.5						
Potassium oxide, K_2O	3.0						
Sulphur, S	0.2						
Total carbon, C	1.0						

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

Physical tests

Tempering water:	About 20 per cent.
Drying linear shrinkage:	About 4 per cent.
Drying volume shrinkage:	About 13 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	1.4	4.1	16.9	Buff
Cone 06	2.6	7.6	14.9	Salmon
Cone 04	4.4	12.6	10.7	Orange red
Cone 03	5.9	16.6	9.2	Red
Cone 3	5.8	16.4	7.0	Rich red
Cone 4	9.0	24.6	2.5	Maroon

Overburning temperature: Cone 6 (1,196°C. or 2,174°F.).
Best apparent burning range: Cone 04 to cone 3 (1,050°C. to 1,145°C. or 1,922°F. to 2,093°F.).
Total linear shrinkage at cone 4: About 13 per cent.
Deformation temperature: Cone 11 (1,285°C. or 2,345°F.).

In the northern part of Perry County sandstone is generally wanting on the Clarion horizon. The sandy shales which make up the member in Harrison, Madison, and Clayton townships generally range in thickness from 25 to 35 feet.

Licking County. The Clarion shale member is relatively unimportant in Licking County as its exposures are found only in the southeastern corner, near the crest of Flint Ridge in Franklin and Hopewell townships.

Muskingum County. The Clarion shale horizon is above drainage in parts of every township west of the Muskingum River in Muskingum County with the exception of Harrison, and it is exposed in Wayne, Washington, Madison, and Adams townships east of this river. The Clarion coal and associated clay which mark the top of the shale horizon are generally wanting but either the overlying Vanport limestone or the Ferriferous ore is usually represented. In a few localities this limestone and ore are replaced by sandstone. The Clarion member in Muskingum County varies in thickness from 15 to 55 feet. It consists of both sandstone and shale. The sandstone phase is best developed along a north and south belt extending through Brush Creek, Wayne, Washington, Madison, and Adams townships.

West of the Muskingum River small deposits of sandstone are found in the upper part of the Clarion horizon but their extent is small. Shale of possible ceramic value is most prominently shown in Newton, Springfield, Hopewell, Falls, Muskingum, and Cass townships. At South Zanesville in Springfield Township the Clarion member has been the source for material used for a number of years at the brick plant formerly owned by the Nicholson Corporation. A measurement of the exposures in the pit is as follows:

		Ft.	In.
Shale, weathered, with concretionary masses of ore		4	0
Clay, gray, plastic	*Clarion*	4	0
Clay, siliceous, ferruginous	*Clarion*	5	0
Shale, gray, very sandy at top	*Clarion*	16	6
Shale, bluish-gray, sandy	*Clarion*	18	6
Bottom of pit		..	..
Shale, gray		1	6
Limestone, *Putnam Hill*		2	0

The Clarion shale was formerly used here for the production of face brick. On July 24, 1929, a sample of Clarion shale was taken from this pit and submitted for tests, the results of which are given below:

Sample No. 36

Tests of Clarion shale from pit formerly owned by the Nicholson Corporation, South Zanesville, Muskingum County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	0.77
Water, combined, H_2O+	4.46
Silica, SiO_2	64.16
Alumina, Al_2O_3	16.98
Titanic oxide, TiO_2	0.92
Phosphorus pentoxide, P_2O_5	0.15
Ferric oxide, Fe_2O_3	3.33
Ferrous oxide, FeO	2.50
Lime, CaO	0.75
Magnesia, MgO	1.60
Sodium oxide, Na_2O	0.49
Potassium oxide, K_2O	2.50
Manganese oxide, MnO	0.07
Sulphur, S	0.09
Carbon dioxide, CO_2	1.00
Carbon, organic, C	0.33

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .147 \\ Na_2O & .029 \\ CaO & .044 \\ MgO & .094 \\ FeO & .324 \\ MnO & .004 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.778 \\ TiO_2 & 0.054 \\ P_2O_5 & 0.009 \end{array}\right.$$

RO .642

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has short plasticity. A badly featheredged column is extruded from the die.

Time of slaking: 16.75 minutes.

Water of plasticity: 17.70 per cent.

Dry shrinkage:

Volume: 7.21 per cent.

Linear: 2.35 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 268 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	27.90	5.68	1.8	14.59	1.92	2.66
04	24.31	9.70	3.1	12.23	1.99	2.60
02	23.18	11.55	3.7	11.68	2.05	2.65
1	21.16	14.25	4.5	10.09	2.10	2.66
3	16.87	16.75	5.3	8.26	2.02	2.44
5	11.16	18.20	5.7	6.31	1.77	1.99
7	11.13	34.08	10.3	4.95	2.25	2.54

Fired modulus of rupture:
Cone 5, 2,628 pounds per square inch.
Fired specific impact strength:
Cone 05, 1.75 centimeter kilograms per square centimeter.
Cone 4, 1.69 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 5, 6,968 pounds per square inch.
Best firing range: Cone 06 to cone 5.
Overfiring temperature: Cone 7.
Pyrometric cone equivalent: Cone 12.

Scumming: Scum occurs on all trials fired to cone 5 and lower. Six pounds of $BaCO_3$ per ton of material is necessary to eliminate scum.

Salt glazing: A good salt glaze is produced at both 2,050°F. and at 2,100°F. The color of the glaze produced at both temperatures is a dark yellowish-green and pinkish-gray grading into a reddish-brown. When $BaCO_3$ is added the color of the glaze formed at 2,100°F. is a light chocolate brown.

Utilization: This shale was not being utilized for ceramic purposes. Possible uses are for face brick, common brick, and possibly for paving brick. The fired material has a rather stony structure. A good red color is developed at cone 02.

In the lower part of the Clarion shale member the material is rather soft and argillaceous and in many localities it is calcareous in composition whereas in the upper part it becomes more sandy and in places approaches a shaly sandstone. In Section 27, Newton Township, the Clarion shale has a thickness varying from 25 to 30 feet. The Clarion coal is well developed at this locality as it has a thickness of as much as 6 feet. From Hopewell Township the Clarion shales extend to the north and east, outcropping near the hilltops in Licking and Jackson townships and at lower levels in Muskingum and Cass townships. East of the Muskingum River sandstones become prominent on the Clarion horizon.

Coshocton County. The Clarion shale horizon outcrops in every township in Coshocton County with the exception of Tiverton, located in the northwest corner. In the western part of the county the exposures are found near the summits of the hills and ridges but due to the eastern inclination of the beds the outcrops are near drainage level in the eastern part. The Clarion coal is only locally developed as is also the overlying Vanport limestone. Good exposures of the Clarion horizon occur along the Muskingum Valley in Franklin and Virginia townships and along Grahams Ridge in Pike and Washington townships. In these areas the

Clarion is composed of somewhat sandy shales which vary from 30 to 45 feet in thickness. The following section was secured by Wilber Stout in Section 3, Bedford Township:

	Ft.	In.
Flint, shaly lime and covered, *Vanport*	5	0
Clay, light	15	0
Shale and covered, *Clarion*	40	0
Lime, *Putnam Hill*	6	6

The Clarion horizon is generally represented by shale in the east central part of Coshocton County where the thickness averages around 25 feet. The following section showing the stratigraphic succession was secured in the southeast corner of White Eyes Township.

	Ft.	In.
Clay, gray, plastic, *Lower Kittanning*	5	0
Shale and covered	6	2
Flint, light gray, *Vanport* horizon	2	0
Shale and covered, *Clarion*	25	0
Limestone, *Putnam Hill*	..	6
Coal, blossom	1	0
Clay, gray, impure	5	2

The Clarion shale has not been utilized for the production of brick or tile in Coshocton County.

Holmes County. From Coshocton County the belt of exposures of the Clarion shale horizon extends north into Holmes County where this member outcrops in every township with the exception of Ripley and Washington in the northwest corner. The base of this shale member is well defined as the Putnam Hill limestone is generally present in good development in this county. Both the Clarion coal and clay as well as the overlying Vanport limestone are generally wanting. The Clarion member in Holmes County is composed almost entirely of shale although locally sandstone lenses occur as in portions of Berlin Township. In Section 32, Salt Creek Township, soft shale with ore nodules extends from the Putnam Hill limestone to the Lower Kittanning coal with a total thickness of 17 feet. In Section 4, Hardy Township, the same interval is composed of soft shale with a total thickness of about 17 feet. The following section from near Easley School in southern Paint Township illustrates the stratigraphic relations:[1]

		Ft.	In.
Coal, somewhat shaly	*Lower Kittanning*	3	4
Shale, gray	*Lower Kittanning*	..	1½
Coal, fair	*Lower Kittanning*	..	2
Clay, gray, siliceous, plastic		6	6
Clay shale with ore balls up to 4 inches in diameter		13	11

[1] This section as well as some of the data given above on Holmes County have been taken from an unpublished manuscript on the Geology of Holmes County by George White.

	Ft.	In.
Limestone, hard, dense, dove gray, fossiliferous, somewhat irregular and platy, *Putnam Hill*	2	8
Clay shale, dark gray	..	3
Shale, black, coaly } *Brookville*	..	1
Clay shale, gray } *Brookville*	..	1½
Coal, fair } *Brookville*	..	2

The shale occurring between the Putnam Hill limestone and Lower Kittanning clay in Holmes County is chiefly of the soft variety which contains a low percentage of sand and coarse silt. It is not used for the production of brick or tile in this county.

Tuscarawas County. The Clarion shale is an important economic asset to Tuscarawas County as it is a source of material for a number of plants that produce brick and tile in large quantities. The exposures of this member are found in the northwest third and in the southwest corner of the county, including Sandy, Lawrence, Franklin, Wayne, Sugar Creek, Dover, Auburn, York, Jefferson, Oxford, and Salem townships. Shale of a somewhat sandy nature characterizes the rock succession in this county from the Putnam Hill limestone to the Lower Kittanning clay, as both the Clarion clay and coal and the Vanport limestone are generally wanting. At Newcomerstown, Oxford Township, Clarion shale was formerly utilized for ceramic products at the plant of the Canton Brick and Fire Proofing Company.

Both the Clarion shale and the Brookville clay have been utilized also at the plant of the Globe Brick Co. for the production of radial chimney block. A section of the exposures in the pit as recorded by Wilber Stout is given below:

	Ft.	In.
Coal, *Lower Kittanning*, average thickness	2	8
Covered interval	53	0
Shale, *Clarion*	15	0
Limestone, *Putnam Hill*	2	8
Coal and bone coal, *Brookville*	..	5
Clay, light, plastic	4	6
Clay, very siliceous	4	0
Sandstone, clay-bonded	2	0

The Clarion shale member furnishes a part of the raw material used at the plant of the Belden Brick Co. at Port Washington in Salem Township. A measurement of the exposures at the plant follows:

	Ft.	In.
Shale, greenish-gray } *Clarion*	16	3
Shale, grayish-blue } *Clarion*	9	9
Bottom of pit	..	..
Shale and covered	6	6
Limestone, *Putnam Hill*	1	3
Shale, black, carbonaceous	..	5
Coal, shaly, *Brookville*	..	4
Clay, reported thickness, *Brookville*	10	0

The plant consists of two units, one of which utilizes the Brookville clay and the other Clarion shale. The capacity of the plant is about 100,000 brick per day. The Kittanning coals are used for fuel for burning the ware. The Clarion shale exposed in the pit and having a thickness of about 26 feet was sampled on September 12, 1929, and the sample was submitted for chemical analysis and other tests. The results follow:

Sample No. 27

Tests of Clarion shale from pit of the Belden Brick Company, near Port Washington, Tuscarawas County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.68
Water, combined, H_2O+...	6.51
Silica, SiO_2..............	58.80
Alumina, Al_2O_3............	18.53
Titanic oxide, TiO_2........	1.05
Phosphorus pentoxide, P_2O_5	0.28
Ferric oxide, Fe_2O_3........	4.40
Ferrous oxide, FeO.......	2.81
Lime, CaO................	0.42
Magnesia, MgO...........	1.92
Sodium oxide, Na_2O.......	0.19
Potassium oxide, K_2O.....	2.41
Manganese oxide, MnO....	0.07
Sulphur, S...............	0.06
Carbon dioxide, CO_2.......	0.98
Carbon, organic, C........	0.22

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .130 \\ Na_2O & .010 \\ CaO & .022 \\ MgO & .104 \\ FeO & .365 \\ MnO & .004 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.173 \\ TiO_2 & 0.056 \\ P_2O_5 & 0.015 \end{array}\right.$$

$$RO \quad .635$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has fair plasticity. A good column is extruded from the die.

Time of slaking: 10.51 minutes.

Water of plasticity: 19.60 per cent.

Dry shrinkage:

Volume: 11.92 per cent.

Linear: 3.83 per cent.

Drying behavior: Not determined.

Dry modulus of rupture: 310 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	22.29	12.34	4.0	11.00	2.15	2.60
04	16.00	16.12	5.1	7.45	2.14	2.55
02	12.70	25.11	7.8	5.71	2.23	2.56
1	10.51	23.77	7.4	4.56	2.26	2.57
3	9.43	25.60	7.9	3.99	2.36	2.60
5	2.49	25.62	7.9	1.05	2.36	2.44
8	1.55	23.33	7.3	0.67	2.30	2.34

Fired modulus of rupture:
Cone 02, 2,091 pounds per square inch.
Cone 4, 3,706 pounds per square inch.
Fired specific impact strength:
Cone 03, 1.43 centimeter kilograms per square centimeter.
Cone 3, 1.15 centimeter kilograms per square centimeter.
Fired crushing strength: Not determined.
Best firing range: Cone 08 to cone 5.
Overfiring temperature: Cone 7.
Pyrometric cone equivalent: Cone 13.
Scumming: Scum occurs on all trials fired to cone 3 and lower but scum is not apparent on trials fired above cone 3.
Salt glazing: The color of the glaze produced at 2,100°F. and at 2,050°F. is a brownish green over gray shading to a reddish brown.
Utilization: This shale was being used for the production of face brick. It can be used also for common brick. On firing the material develops a good red color at cone 1.

The Clarion shale is above drainage along Stone Creek in York Township and in the northeast quarter of Jefferson Township. Shale from this horizon is being utilized with good results by the Stone Creek Brick Co., located at Stone Creek, Jefferson Township, for the manufacture of face brick. The general stratigraphic relations farther to the north in this county are represented by the following section secured by Wilber Stout in Section 19, Dover Township:

		Ft.	In.
Coal blossom, *Lower Kittanning*		1	0
Clay, plastic, with some boulders of flint clay, *Lower Kittanning*		10	0
Covered		8	0
Shale with large concretions irregularly distributed		17	0
Ore, nodular		..	6
Shale, gray, with some ore nodules		19	6
Lime, *Putnam Hill*		1	0
Coal blossom, *Brookville*		1	0
Clay, plastic, part covered	*Brookville*	7	0
Clay, light, siliceous	*Brookville*	7	0

Sugar Creek in Sugar Creek Township is the location of important brick and tile plants which are supplied in part with Clarion shale. Plants Nos. 1 and 2, of the Finzer Bros. Clay Co. use both the Brookville clay and Clarion shale for their products. A section of the rock exposures is as follows:

		Ft.	In.
Shale, greenish gray, sandy	*Clarion*	18	0
Limestone, impure, fossiliferous, ferruginous	*Clarion*	..	8
Shale, gray	*Clarion*	4	0
Shale, dark, carbonaceous, fossiliferous	*Clarion*	2	0
Limestone, dark, *Putnam Hill*		1	2
Shale, black		..	2
Coal, *Brookville*		1	0
Clay, plastic, upper part dark	*Brookville*	4	6
Clay, siliceous	*Brookville*	4	6

The Brookville clay is used to produce the light shades of brick and the Clarion shale for the reds and reddish brown colors. The capacity of the plants is about 140,000 brick a day. The Bedford coal is mined near the plant and used for fuel. A sample of the Clarion shale was cut on August 7, 1929, and submitted for testing. The results of the tests are given below:

Sample No. 30

Tests of Clarion shale from pit of the Finzer Brothers Clay Company, Sugar Creek, Tuscarawas County.

Chemical analysis *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.75
Water, combined, H_2O+	5.40
Silica, SiO_2	58.17
Alumina, Al_2O_3	19.29
Titanic oxide, TiO_2	1.14
Phosphorus pentoxide, P_2O_5	0.12
Ferric oxide, Fe_2O_3	6.86
Ferrous oxide, FeO	1.33
Lime, CaO	0.49
Magnesia, MgO	1.60
Sodium oxide, Na_2O	0.14
Potassium oxide, K_2O	3.20
Manganese oxide, MnO	0.03
Sulphur trioxide, SO_3	trace
Carbon dioxide, CO_2	0.15
Carbon, organic, C	0.44

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .166 \\ Na_2O & .007 \\ CaO & .025 \\ MgO & .083 \\ FeO & .389 \\ MnO & .001 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.015 \\ TiO_2 & 0.059 \\ P_2O_5 & 0.006 \end{array}\right.$$

RO .671

Physical properties, determined by Chester R. Austin
Properties in green state

Workability: A fair column is extruded from the die.
Time of slaking: 9.60 minutes.
Water of plasticity: 19.47 per cent.
Dry shrinkage:
  Volume: 10.65 per cent.
  Linear: 3.43 per cent.
Drying behavior: This material dries satisfactorily with ordinary care.
Dry modulus of rupture: 284 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	22.10	16.90	5.3	10.49	2.12	2.70
04	14.24	22.36	6.9	6.29	2.26	2.64
02	10.77	24.06	7.5	4.67	2.32	2.60
1	6.53	25.91	8.0	2.77	2.37	2.54
3	3.35	26.81	8.2	1.40	2.39	2.47
5	1.98	26.60	8.2	0.84	2.36	2.40
7	8.50	17.64	5.5	3.78	2.12	2.31

Fired modulus of rupture:
  Cone 04, 3,686 pounds per square inch.
  Cone 5, 4,770 pounds per square inch.

Fired specific impact strength:
Cone 05, 1.45 centimeter kilograms per square centimeter.
Cone 5, 1.28 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 5, 18,684 pounds per square inch.
Best firing range: Cone 08 to cone 5.
Overfiring temperature: Cone 7.
Pyrometric cone equivalent: Cone 13.

Scumming: Scum occurs on all trials fired to cone 2 and lower but scum is not apparent on trials fired above cone 2. Two pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The salt glaze produced at 2,100°F. has a reddish brown color whereas that produced at 2,050°F. has a brown color with same orange mottling. When $BaCO_3$ is added the glaze produced at 2,100°F. has a chocolate brown color.

Utilization: This shale was being used for the production of face brick. It can be used for making common brick. On firing the material develops a good red color at cone 02.

Clarion shale has been used for a number of years to supply in part the raw material for the plants of Shepfer and Moomaw Bros., located at Sugar Creek. In addition to this shale, both the Brookville clay and the Homewood shale are also utilized. A measurement of the exposures is as follows:

		Ft.	In.
Shale, gray *Clarion*		11	0
Limestone, *Putnam Hill*		1	1
Shale, gray, calcareous		..	3
Shale, black, and shaly coal, *Brookville*		..	10
Clay, bluish gray, siliceous, *Brookville*		12	0
Shale, greenish gray, ferruginous, sandy	*Tionesta*	17	6
Shale, dark, carbonaceous, with ore nodules	*Tionesta*	7	0
Bottom of pit	*Tionesta*	..	..
Shale, dark, carbonaceous	*Tionesta*	3	0
Coal	*Bedford*	1	4
Shale parting	*Bedford*	..	3
Coal	*Bedford*	2	11
Shale, black, bituminous		..	3
Clay, weathered, *Bedford*		4	6

The Clarion shale outcrops over a large area in Tuscarawas County north and northeast of Sugar Creek, including Wayne, Franklin, Lawrence, and Sandy townships. This shale has been utilized at Bolivar for a number of years by the Bolivar Clay Products Co. for the manufacture of building tile. The following section is a record of the exposures at the plant as secured by Wilber Stout:

		Ft.	In.
Limestone, shaly, fossiliferous, *Vanport*		3	0
Clay shale	*Clarion*	1	0
Shale	*Clarion*	14	0
Shale, ferruginous, with boulders of limestone	*Clarion*	..	8
Shale	*Clarion*	13	6

Limestone	*Putnam Hill*	1	9
Limestone, shaly		..	3
Shale, bony		..	8
Coal, *Brookville*, reported thickness		2	4
Clay, shale, sandstone, and covered		33	6
Flint, black, *Upper Mercer*		..	6
Coal blossom, shaly, *Bedford*		1	0
Clay, siliceous		2	0
Shale and shaly sandstone		25	0
Limestone, *Lower Mercer*		2	6

Wayne County. The horizon of the Clarion shale is due to outcrop in parts of Sugar Creek, Paint, Salt Creek, and Franklin townships, Wayne County. In this area, however, the Clarion coal and clay and the Vanport limestone are wanting and the Middle Kittanning coal is separated from the Putnam Hill limestone by a short interval of 15 to 30 feet of strata which are composed chiefly of sandstone.

Stark County. The Clarion shale horizon outcrops over a large area in Stark County but its present economic importance is centered in that part which lies south of an east-west line passing through the northern edge of Canton. North of this line the surface is covered with glacial drift and little is known about the bedrock below. South of this line outcrops of the Clarion horizon are present above drainage in Tuscarawas, Sugar Creek, Perry, Bethlehem, Pike, Canton, Sandy, and Osnaburg townships. In the southwestern part of the county the horizon outcrops near the summits of the hills and ridges but due to the easterly slope of the beds the exposures occur at lower levels in the south central and southeastern portions. The economic development of the Clarion shale resources of Stark County is centered chiefly in Pike and Canton townships.

In Section 27, Pike Township, the Clarion shale is utilized by the Sparta Ceramic Co. and by the United States Quarry Tile Co. for the manufacture of quarry tile. The material is of the bluish gray siliceous variety which yields a satisfactory product. A section of the exposures in the pit of the Sparta Ceramic Co., as measured by Wilber Stout, is given below:

		Ft.	In.
Shale, *Clarion*		20	0
Limestone, *Putnam Hill*		4	0
Coal, *Brookville*		1	6
Clay, plastic	*Brookville*	3	0
Clay, light, siliceous		6	0

In Section 11, Pike Township, gray sandy shale, with a thickness of about 40 feet, occurs between the Putnam Hill limestone and Lower Kittanning clay. The Clarion shale has been used for the manufacture of face brick and building tile at the plant of the Preston Clay Company located in the southern part of Section 27, Canton Township. The outcrops in the pit are reported by Wilber Stout to have the character and thickness described below:

		Ft.	In.
Shale, gray, *Clarion*		20	0
Limestone, *Putnam Hill*		3	6
Shale, calcareous		..	2
Coal, *Brookville*		1	5
Clay, light, plastic	*Brookville*	3	6
Clay, light, very siliceous	*Brookville*	8	0
Sandstone, shaly		13	0
Shale and covered		18	0

The Brookville clay was formerly worked at this plant and sold to the trade.

At Canton and vicinity the Clarion shale supplies the raw material for a large industry in the manufacture of paving block and face brick. In the southern edge of Canton the Metropolitan Paving Brick Co. operates four plants on the Clarion shale, two of which are located in Section 15, one in Section 17, and one in Section 20, Canton Township. The characteristics of the shale are much the same at these four plants. The material works well and produces a paving block of good quality. The rock succession at the Royal plant in the southeastern part of Section 17 is reported by Wilber Stout as follows:

		Ft.	In.
Shale, gray, somewhat sandy, *Clarion*		48	0
Lime, *Putnam Hill*		4	0
Coal, *Brookville*		1	8
Clay, plastic, very good	*Brookville*	4	0
Clay, very siliceous	*Brookville*	4	0
Clay, siliceous, gray	*Brookville*	4	0

In the east central part of Section 15, Canton Township, the Clarion shale is used at the plant of the Belden Brick Co. The character and thickness of the deposits are shown in the following record of the outcrops in the pit:

	Ft.	In.
Glacial drift	4	0
Shale, weathered	6	0
Shale, bluish-gray, a little sandy	8	0
Limestone, fossiliferous, ferruginous, irregular in thickness	1	0
Shale, bluish-gray, a little sandy	13	0
Bottom of pit	..	..
Shale, bluish-gray, a little sandy	2	9
Limestone, *Putnam Hill* not entire thickness	2	0

The bed of limestone which lies about 13 feet above the bottom of the pit varies much in thickness from place to place and in parts of the pit it is wanting. As it breaks up into large rectangular blocks, it is easily separated from the shale and discarded. Face brick in various shades of red and reddish brown is the chief product of the plant, although flesh colors are also produced. The capacity is about 65,000 brick per day. A sample of the Clarion shale was cut from the exposures at this place on September 6, 1929, and submitted for testing. The results are given below:

Sample No. 26

Tests of Clarion shale from pit of the Belden Brick Company, Canton, Stark County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.16
Water, combined, H_2O+...	5.50
Silica, SiO_2..............	60.04
Alumina, Al_2O_3...........	18.80
Titanic oxide, TiO_2........	1.20
Phosphorus pentoxide, P_2O_5	0.27
Ferric oxide, Fe_2O_3........	3.29
Ferrous oxide, FeO.......	2.84
Lime, CaO................	0.68
Magnesia, MgO...........	1.53
Sodium oxide, Na_2O.......	0.22
Potassium oxide, K_2O.....	2.99
Manganese oxide, MnO....	0.05
Sulphur, S................	0.09
Carbon dioxide, CO_2.......	0.75
Carbon, organic, C........	0.81

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .159 \\ Na_2O & .012 \\ CaO & .036 \\ MgO & .081 \\ FeO & .308 \\ MnO & .003 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.193 \\ TiO_2 & 0.064 \\ P_2O_5 & 0.014 \end{array}\right.$$

RO .599

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has rather short plasticity. A badly featheredged column is extruded from the die.

Time of slaking: 6.75 minutes.

Water of plasticity: 19.32 per cent.

Dry shrinkage:

Volume: 10.14 per cent.

Linear: 3.27 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 340 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	25.11	10.43	3.4	12.95	1.95	2.62
04	20.62	13.40	4.3	10.09	2.20	2.58
02	15.71	18.03	5.7	7.33	2.22	2.56
1	11.72	21.89	6.8	5.19	2.27	2.56
3	8.63	25.00	7.7	3.66	2.36	2.57
5	1.24	24.45	8.1	0.52	2.38	2.41
7	3.22	20.62	6.5	1.49	2.23	2.30
8	4.23	18.70	5.9	1.97	2.16	2.24

Fired modulus of rupture:
Cone 02, 2,856 pounds per square inch.
Cone 3, 3,805 pounds per square inch.
Fired specific impact strength:
Cone 03, 1.45 centimeter kilograms per square centimeter.
Cone 3, 0.821 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 3, 18,642 pounds per square inch.
Best firing range: Cone 06 to cone 3.
Overfiring temperature: Cone 5.
Pyrometric cone equivalent: Cone 10.

Scumming: A scum occurs on all trials fired to cone 3 and lower but scum is not apparent on trials fired above cone 3. Three pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The salt glaze which develops at 2,100°F. and at 2,050°F. is of a brownish green on gray color with some orange brown mottling. When $BaCO_3$ is added the glaze produced at 2,100°F. has a dark chocolate brown color.

Utilization: This material was used for the manufacture of face brick. It can be used also for common brick. On firing the material develops a good red color at cone 1.

The Clarion shale furnishes the raw materials for the manufacture of face brick at the Canton plant of the Canton Brick and Fireproofing Co., located in Section 32, Plain Township.

Portage County. The horizon of the Clarion shale is due near the surface in the southeast corner of Portage County, but the deposits of glacial drift prevent definite knowledge of the character, exact distribution, or thickness of the deposits.

Mahoning County. In Mahoning County the Clarion shale member lies near the surface in parts of Poland, Boardman, Springfield, Beaver, Green, Goshen, and Smith townships. As the region is drift covered and as the topography is generally flat or gently rolling, few exposures occur.

The Brookville coal is poorly exposed in Mahoning County but the Vanport limestone is well developed in Poland Township near Lowellville, where it was quarried for a number of years. The Clarion shale which occurs between these members has not been utilized in the county.

Columbiana County. The distribution of the Clarion shale outcrops in Columbiana County is limited to the Beaver Valley in St. Clair Township and to the Ohio River Valley in Liverpool Township as far west as East Liverpool. The average thickness of this member is about 17 feet. The general succession is illustrated by the following section secured near the mouth of Bieler Run in Section 12, St. Clair Township:[1]

[1] Geol. Survey Ohio, 4th Ser., Bull. 28, pp. 52-53, 1924.

		Ft.	In.
Shale, black, fossiliferous	*Vanport*	1	4
Shale, gray, siliceous	*Vanport*	8	2
Ore, nodular, fossiliferous	*Vanport*	..	2
Shale and shaly sandstone, *Clarion*		8	2
Clay, plastic, siliceous, *Clarion*		6	0
Sandstone, thin-bedded to shaly		28	6
Clay shale, dark, with thin layers of shaly coal, *Tionesta*		..	8

The Clarion shale is not being utilized in Columbiana County for the manufacture of ceramic products.

Lower Kittanning Shale

The stratigraphic position of the Lower Kittanning shale, as that term is used in this report, is in the interval between the Clarion coal horizon below and the Lawrence clay above. In part of the outcrop area in Ohio this interval consists of shale, but in some localities massive sandstone is present which fills a part of the interval and which is known as the Lower Kittanning sandstone. The thickness of the Lower Kittanning sandstone and shale horizon is quite variable in this State, but averages about 10 feet. Outcrops are due in Scioto, Lawrence, Gallia, Vinton, Jackson, Hocking, Perry, Muskingum, Coshocton, Holmes, Tuscarawas, Carroll, Wayne, Stark, Mahoning, and Columbiana counties.

The top of the Lower Kittanning shale is clearly defined across Ohio as either the Lawrence clay or the overlying Lower Kittanning clay is invariably present on the outcrop. The underlying Clarion coal or clay is generally well shown from the Ohio River north through Scioto, Lawrence, Gallia, Jackson, and Vinton counties. This coal and clay are patchy in distribution through Hocking, Athens, and Perry counties; are seldom present in Muskingum, Coshocton, Holmes, Tuscarawas, Wayne, and Stark counties; but appear again with fair continuity in Mahoning and Columbiana counties. Close above the Clarion coal there are a limestone and an overlying iron ore, known as the Vanport and Ferriferous respectively, which are well developed over large areas. The Vanport limestone is generally present in Scioto, Lawrence, Gallia, and Jackson counties, where it lies immediately above the Clarion coal. In northern Jackson, Vinton, and parts of Perry counties where the Vanport limestone is locally developed, it is separated from the Clarion coal by a short shale interval. Embedded in this shale at places is a thin coal bed known as the Scrubgrass. Where these beds are all represented as in parts of Vinton County, the succession in ascending order is Clarion coal, shale, Scrubgrass coal, shale, Vanport limestone, Ferriferous ore, shale, and Lawrence clay. In Hocking, Perry, Muskingum, and Coshocton counties the Vanport limestone is of little value as it is always thin and as it is wanting over large areas. Throughout the outcrop areas in Tuscarawas, Holmes, Wayne, and Stark counties, this limestone is generally wanting from the section, but it appears again in strong development in eastern Mahoning County and it is generally present on the outcrop in Columbiana County. On the whole the presence of the Vanport limestone is of little detriment to the Lower Kittanning shale. The Ferriferous ore is of chief importance as a stratigraphic unit in Scioto, Lawrence, Gallia, Jackson, and Vinton counties where it lies immediately above the Vanport limestone. As the Lower Kittanning shale horizon is thin and ill defined in part of the outcrop areas and as the material from this horizon is being utilized at only one locality in Ohio, the features of the bed will be traced in a very general way.

The Lower Kittanning shale horizon has small areal extent in Scioto County for it is found only near the summits of the highest knobs and ridges in Vernon, Green, and Bloom townships. In Lawrence County the member consists of both sandstone and shale which outcrop in Perry, Upper, Hamilton, Elizabeth, Aid, Decatur, Symmes, and Washington townships. The average thickness is about 15 feet. One mile east of the tunnel on the Ironton-Hecla road in Upper Township, the material is a soft shale with a thickness of 15 feet. At the tunnel on the Detroit, Toledo and Ironton Railroad near Royersville, Elizabeth Township, the Lower Kittanning shale member is represented by about 3 feet of soft shale. In Washington Township some sandstone is present as shown in the following section secured near Olive Furnace.[1]

		Ft.	In.
Shale, gray		12	0
Coal blossom, *Lower Kittanning*		2	0
Clay, plastic, good, *Lower Kittanning*		4	0
Clay shale, siliceous		3	0
Coal blossom, *Lawrence*		..	6
Clay, plastic, good, *Lawrence*		5	6
Sandstone, white, clay bond	*Lower Kittanning*	5	0
Shale, with parts covered	*Lower Kittanning*	6	0
Limestone, *Ferriferous*		5	0

In Gallia County the outcrops of the Lower Kittanning shale horizon are restricted in extent to the northwestern part of Greenfield Township, to the valleys of Symmes Creek in Walnut Township, and Little Raccoon Creek in Huntington Township. The material consists of sandstone and shale with an average thickness of about 16 feet. In Jackson County outcrops of the Lower Kittanning shale horizon occur in eastern Jefferson and Franklin townships and through Madison, Bloomfield, and Milton townships. Much variation in thickness is found but the average is about 20 feet. Sandstone is present in parts of the county but it is somewhat local in extent. At the mines of the Diamond Brick Company at Oak Hill, Jefferson Township, the horizon is represented by 5 feet of sandy shale above which is 8 feet of clay-bonded sandstone. In Section 19,

[1] Geol. Survey Ohio, 4th Ser., Bull. 20, p. 365, 1916.

Madison Township, the material is chiefly a sandy shale. The general features are shown by the following record from Section 9, Madison Township.[1]

	Ft.	In.
Clay, *Oak Hill*	3	0
Shale	11	6
Coal, *Lower Kittanning*	..	9
Clay, plastic, good	4	9
Shale, sandy, *Lower Kittanning*	16	0
Limestone, *Vanport (Ferriferous)*	4	0

In Vinton County the Lower Kittanning shale horizon outcrops in Wilkesville, Richland, Clinton, Vinton, Elk, Madison, Jackson, Swan, and Brown townships. In this county the Vanport is separated from the Clarion coal by carbonaceous shale which has an average thickness of about 8 feet. The Scrubgrass coal occurs at some localities embedded in this carbonaceous shale. Above the Vanport limestone and the overlying Ferriferous ore the material is sandstone and sandy shale. Near Hope Station in Brown Township the Lower Kittanning member is represented by 18 feet of sandy shale underlain by massive sandstone. In Section 30, Madison Township, massive sandstone has entirely replaced the shale. Much the same condition exists at Oreton in Vinton Township. The following record from Section 23, Brown Township, illustrates the stratigraphic succession:[2]

	Ft.	In.
Coal, weathered, *Lower Kittanning*	..	6
Clay, plastic, light	9	6
Sandstone, massive, soft	33	0
Shale, gray, siliceous	7	4
Ore, nodular	..	1
Shale, dark gray, siliceous	..	10
Coal, shaly, *Scrubgrass*	..	8
Shale, dark, part covered	3	1
Shale, black, somewhat fissile	3	11
Shale, bony, blocky	1	3
Coal, *Clarion*	..	10
Clay, plastic	6	0

The Lower Kittanning shale horizon is above drainage in parts of Washington, Starr, Green, Ward, and Falls Gore townships, Hocking County, but in Green and Falls Gore townships the member is either reduced in thickness or is entirely missing as the Clarion coal and clay, the Vanport limestone, and Ferriferous ore are wanting and as the Lower Kittanning coal lies above the Putnam Hill limestone. In Washington and Starr townships the Vanport limestone and overlying ore are either wanting from the section or are found close below the Lawrence clay. In

[1] Geol. Survey Ohio, 4th Ser., Bull. 20, p. 235, 1916.
[2] Geol. Survey Ohio, 4th Ser., Bull. 31, p. 250, 1927.

Section 13, Washington Township, the Clarion coal is overlain with 43 feet of sandy shale and a few beds of shaly sandstone. At a few places the Scrubgrass coal occurs a few feet above the Clarion coal and separated from it by dark carbonaceous shale. Four feet of such shale is found above the Clarion coal in Section 33, Starr Township, above which is 15 feet of gray sandy shale. A similar condition exists at other places in Starr Township. In Perry County exposures of the Lower Kittanning shale horizon are found in Coal, Monday Creek, Salt Lick, Jackson, Pike, Bearfield, Clayton, Harrison, and Madison townships, but bodies of sandstone of somewhat local extent are present throughout the area. The Clarion coal and clay are wanting and the Vanport limestone lies close below the Lawrence clay. In Section 32, Jackson Township, the Putnam Hill limestone is overlain with 70 feet of sandy shale a part of which is Lower Kittanning in age. In Section 12, Monday Creek Township, the Lower Kittanning member is made up of massive sandstone. Bodies of sandy shale are present on this horizon in every township in Perry County where exposures occur.

The Lower Kittanning shale horizon is of little value in Muskingum County as it is generally only a few feet in thickness and as in some localities it is very poorly defined. The Clarion coal is of no importance except over a small area in Hopewell Township and the Vanport, although more persistent than the underlying coal, is subject to many wants. Exposures of the horizon are present in Newton, Clay, Brush Creek, Springfield, Hopewell, Wayne, Falls, Washington, Muskingum, Cass, Madison, Adams, and Monroe townships. Beds of shale of possible ceramic value are present on the Lower Kittanning horizon in parts of Cass and Madison townships. The following section was secured by Wilber Stout about one mile south of Elberson School in the central part of Cass Township.

		Ft.	In.
Limestone, nodular, gray, *Hamden*		1	0
Clay and covered		3	0
Shale, *Lower Kittanning*		10	6
Flint, with *fusulina*	*Vanport*	..	8
Limestone, gray, nodular, fossiliferous	*Vanport*	1	0
Shale		41	0
Limestone, *Putnam Hill*		4	0

The Lower Kittanning shale has not been utilized for ceramic purposes in Muskingum County. In Coshocton County much the same condition prevails as is found in Muskingum County, as the Vanport limestone and Clarion coal are wanting over large areas and as the interval between the limestone and the Lower Kittanning clay is small. Both the Clarion coal and clay and the Vanport limestone are generally wanting on the outcrop areas in Holmes, southeastern Wayne, Tuscarawas, Stark, and western Carroll counties and, therefore, the Lower Kittanning shale can not be separated from the underlying Clarion shale. About one-half mile north of Baltic in the southern part of Section 25, Clark Township, Holmes County, the shale lying close below the Lower Kittanning clay is worked by the General Clay Products Company for building block and drain tile. The capacity of the plant is about 38,000 feet of 3-inch tile per day. A section of the exposures in the pit is given below:

		Ft.	In.
Shale, gray, sandy		26	0
Shale, bluish-gray, with ore nodules		8	6
Shale, black, carbonaceous		2	0
Coal, weathered, *Middle Kittanning*		3	0
Clay, ferruginous, siliceous		5	0
Clay and covered		14	9
Coal, *Lower Kittanning*, not entire thickness		1	0
Covered interval		9	6
Shale, greenish-gray, sandy	*Lower Kittanning*	19	3
Shale, bluish-gray, with a few thin layers of iron carbonate	*Lower Kittanning*	4	0

Both the Middle Kittanning clay and the shale above the Middle Kittanning coal have been utilized at this plant, but in 1929 the Lower Kittanning shale was used exclusively. A sample of Lower Kittanning shale from this pit was cut on August 6, 1929. It was submitted for testing with the following results:

Sample No. 31

Tests of Lower Kittanning shale from pit of the General Clay Products Company near Baltic, Holmes County

Chemical analysis

Downs Schaaf, analyst

Water, hydroscopic, H_2O-	0.92
Water, combined, H_2O+	5.60
Silica, SiO_2	59.82
Alumina, Al_2O_3	19.29
Titanic oxide, TiO_2	1.27
Phosphorus pentoxide, P_2O_5	0.16
Ferric oxide, Fe_2O_3	4.92
Ferrous oxide, FeO	1.74
Lime, CaO	0.56
Magnesia, MgO	1.80
Sodium oxide, Na_2O	0.39
Potassium oxide, K_2O	2.90
Manganese oxide, MnO	0.07
Sulphur trioxide, SO_3	0.19
Carbon dioxide, CO_2	0.29
Carbon, organic, C	0.22

Oxide ratio

K_2O	.150	Al_2O_3	1.00	SiO_2	3.101
Na_2O	.020			TiO_2	0.065
CaO	.029			P_2O_5	0.009
MgO	.093				
FeO	.320				
MnO	.004				
RO	.616				

Physical properties, determined by Chester R. Austin
Properties in green state

Workability: This material has fair plasticity. A good column is extruded from the die.

Time of slaking: 11.76 minutes.

Water of plasticity: 20.57 per cent.

Dry shrinkage:

Volume: 10.90 per cent.

Linear: 3.51 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 317 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	24.68	12.47	4.0	12.24	2.01	2.68
04	17.20	18.63	5.9	8.00	2.15	2.60
02	14.81	21.58	6.7	6.73	2.24	2.63
1	12.29	23.83	7.4	5.46	2.31	2.64
3	9.96	25.40	7.8	4.19	2.37	2.64
5	6.14	25.63	7.9	2.58	2.38	2.53
7	5.10	25.38	7.8	2.20	2.33	2.45

Fired modulus of rupture:

Cone 02, 2,513 pounds per square inch.

Cone 5, 3,505 pounds per square inch.

Fired specific impact strength:

Cone 03, 1.08 centimeter kilograms per square centimeter.

Cone 4, 1.24 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 5, 16,449 pounds per square inch.

Best firing range: Cone 06 to cone 5.

Overfiring temperature: Cone 7.

Pyrometric cone equivalent: Cone 13-14.

Scumming: Scum occurs on all trials fired to cone 2 and lower but scum is not apparent on trials fired above cone 2. One pound of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The salt glaze produced at 2,050°F. has a dark brown color. The glaze produced at 2,100°F. is a yellowish green and pinkish gray mottle on a reddish brown background. When $BaCO_3$ is added the glaze produced at 2,100°F. has a chocolate brown color.

Utilization: This shale was being used for the production of drain tile. It can be used also for face brick, common brick, and possibly for hollow tile. The fired material develops a good red color at cone 02.

In Mahoning County the Lower Kittanning shale is due to outcrop in Smith, Goshen, Green, Canfield, Beaver, Boardman, Springfield, and Poland townships, but due to deposits of glacial drift at the surface very few exposures occur. The Lower Kittanning coal and clay have been utilized at Greenford in Green Township and at Canfield in Canfield Township. Near Lowellville in the eastern part of Poland Township the Vanport limestone, which lies at the base of the Lower Kittanning shale, was quarried for a number of years for various purposes. The overlying material in this locality is a somewhat sandy shale. The following section shows the nature of the Lower Kittanning horizon along Indian Run about 3½ miles southwest of Boardman:

		Ft.	In.
Shale, weathered		5	0
Coal, weathered, *Lower Kittanning*		1	8
Clay		5	0
Shale and covered	*Lower Kittanning*	13	0
Sandstone and covered		20	0
Lime, *Vanport*		1	0

Shale on the Lower Kittanning horizon has not been utilized for economic purposes in Mahoning County.

The chief areas of exposure of the Lower Kittanning shale horizon in Columbiana County are located along Beaver River and its branches in Elk Run, southern Middleton, and St. Clair townships, and along the Ohio River Valley from the state line to Wellsville, including parts of Liverpool and Yellow Creek townships. The member is well defined as the underlying Clarion coal and Vanport limestone and the overlying Lawrence or Lower Kittanning clays are generally present. The horizon consists of both sandstone and sandy shale, having an average thickness of about 64 feet. The sandstone phase is best developed along the Ohio River Valley from East Liverpool to Wellsville. In this area it becomes massive in character and in places measures over 100 feet in thickness. From East Liverpool to the State line the Lower Kittanning consists of sandy shale with some shaly sandstone. Sandy shale also characterizes this member along the valley of Middle Fork west of Elkton in Elk Run Township, and from Park to St. Clair in St. Clair Township. Shale of similar character is found along North Fork in Middleton Township and in local areas from St. Clair south along the Beaver Valley to Smith's Ferry. The general character of the rock succession is illustrated by the following section secured along Bieler Run near St. Clair, St. Clair Township.

		Ft.	In.
Shale, bony		..	7
Coal, *Lower Kittanning*		1	10
Clay, gray, plastic	*Lower Kittanning*	7	2
Clay, shaly		1	0
Clay, dark		..	10
Clay, gray, plastic		5	5
Sandstone, shaly, and shale, siliceous	*Lower Kittanning*	25	0
Shale, parts covered		23	8
Shale, black, fossiliferous	*Vanport*	1	4
Shale, gray, siliceous		8	2
Ore, nodular, fossiliferous		..	2
Shale and shaly sandstone		8	2
Clay, plastic, siliceous, *Clarion*		6	0

Middle Kittanning shale immediately overlying the Clarion clay was formerly used at East Liverpool by the East Liverpool Brick Manufacturing Company for the manufacture of face brick. Material from this horizon has not been utilized at any other place in Columbiana County.

Strasburg Shale

Overlying the Lower Kittanning coal horizon and extending upward to the next persistent and widely distributed member, the Middle Kittanning clay, is a series consisting chiefly of shale with ironstone concretions, known as Strasburg shale, but also containing sandstone, limestone, coal, and clay of more or less wide-spread but patchy distribution. When a complete series occurs the succession from the Lower Kittanning coal upward is as follows: Hamden limestone, shale, Oak Hill clay, Strasburg coal, shale, Salem limestone, and Middle Kittanning clay. Of these various members the Oak Hill clay is perhaps the most widely distributed. The usual position of this clay is close above the Lower Kittanning coal or, where that coal is wanting, close above the Lower Kittanning clay. At places, however, the Oak Hill is separated from the Lower Kittanning by a short shale interval. Thus in northern Jackson and in Vinton counties as well as in parts of Hocking, Athens, Perry, and Columbiana counties the Oak Hill is separated from the Lower Kittanning by an interval varying from 10 to 25 feet. In Stark and Tuscarawas counties its position is about midway between the Lower and Middle Kittanning coals.

In Perry, Muskingum, and Coshocton counties in the central part of the belt of outcrops, the Hamden limestone of marine origin occurs either at the base of the Oak Hill clay or it is embedded within that member. Where the Oak Hill clay is wanting the Hamden limestone is found at places close above the Lower Kittanning coal. Beds of iron ore occur on the Hamden horizon in parts of southern Ohio. In Columbiana County the thin Salem limestone of fresh water origin is present close below the Middle Kittanning clay. Nodular clay ironstone without definite stratigraphic significance is of common occurrence embedded in the Strasburg shale.

The upper and lower limits of the Strasburg shale member are clearly defined across the State, as both the Lower and Middle Kittanning coals are present on the outcrop with few wants from Jefferson, Columbiana, and Mahoning counties on the east to Lawrence County on the south. The thickness of the horizon is variable from place to place, but averages about 20 feet. Bodies of sandy shale are found at various places both above and below the Oak Hill member, but the material does not add greatly to the ceramic products of the State as it is being utilized in Jackson, Muskingum, Stark, and Mahoning counties only. The character and stratigraphy of the member are traced by counties.

Scioto, Lawrence, and Gallia Counties. The areal extent of the Strasburg shale horizon in Scioto County is small as outcrops are limited to the highest elevations in northeastern Bloom, eastern Vernon, and southeastern Green townships. From Scioto County the belt of outcrops extends into western Lawrence County where exposures are found in Perry, Lawrence, Upper, Hamilton, Elizabeth, Decatur, and Washington townships and along the Symmes Creek Valley in Aid and Symmes townships. The Strasburg member in this county is chiefly sandstone, although sandy shale is locally developed. The thickness is about 40 feet. Much the same conditions prevail on the outcrop through Greenfield, Huntington, and Walnut townships, Gallia County. Local deposits of sandy shale are present as shown by the following record secured at Miller's Ford in Walnut Township.[1]

	Ft.	In.
Coal and partings, *Middle Kittanning*	3	5
Shale and covered	25	0
Shales, sandy	10	0
Sandstone, shaly	5	0
Covered	3	0
Coal blossom, *Lower Kittanning*	2	0
Clay	2	0

Jackson County. The distribution of the outcrops of the Strasburg horizon in Jackson County includes small patches in eastern Jefferson Township and larger areas in Madison, Bloomfield, and Milton townships. The thickness of the member averages about 39 feet in this county. Much sandstone is present on the horizon, but it is generally local in extent, grading laterally into sandy shale which in turn is often replaced by sandstone in a short horizontal distance. Over small areas in Bloomfield Township the entire member is composed of massive sandstone. Near Cambria Furnace in Section 36, Jefferson Township, the Middle Kittanning clay is underlain by 14 feet of shale which is in part sandy in character. Near the mines of the Ohio Fire Brick Company, located in Section 19, Madison Township, the Strasburg member is represented by 20 feet of shale below which is 5 feet of sandstone. The beds overlying the Lower Kittanning coal are a source of raw material used in the plant of Wm. E. Dee Co., located in Section 24, Jefferson Township. A section of the exposures in the pit is given below:

		Ft.	In.
Shale, gray, sandy		15	6
Clay, ferruginous, with ore nodules	*Oak Hill*	1	3
Clay, bluish-gray, sandy	*Oak Hill*	1	3
Shale, sandy, micaceous		4	3
Shale, soft		2	10
Flint		..	6
Clay, gray		..	8

[1] Geol. Survey Ohio, 4th Ser., Bull. 20, pp. 623-624, 1916.

		Ft.	In.
Coal	Lower Kittanning	1	11
Parting	Lower Kittanning	..	8
Coal	Lower Kittanning	..	7
Clay, *Lower Kittanning*		7	10

The Lower Kittanning clay is used in the plant for the manufacture of fire brick and the beds above the Lower Kittanning coal, including the Oak Hill clay and the overlying shale, are utilized in the proportions delivered by the shovel for the production of sewer pipe and building block. The beds above the Lower Kittanning coal described in the above section were sampled on June 20, 1929, and the sample was submitted for testing. The results of the various tests are given below:

Sample No. 29

Tests of Strasburg shale and Oak Hill clay from pit of Wm. E. Dee Company, Oak Hill, Jackson County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	2.05
Water, combined, H_2O+	5.63
Silica, SiO_2	58.01
Alumina, Al_2O_3	22.14
Titanic oxide, TiO_2	1.29
Phosphorus pentoxide, P_2O_5	0.17
Ferric oxide, Fe_2O_3	3.58
Ferrous oxide, FeO	0.65
Lime, CaO	1.16
Magnesia, MgO	1.83
Sodium oxide, Na_2O	0.20
Potassium oxide, K_2O	2.82
Manganese oxide, MnO	0.04
Sulphur trioxide, SO_3	0.12
Carbon dioxide, CO_2	0.35
Carbon, organic, C	0.19

Oxide ratio

K_2O	.127	Al_2O_3	1.00	SiO_2	2.620
Na_2O	.009			TiO_2	0.058
CaO	.052			P_2O_5	0.008
MgO	.083				
FeO	.175				
MnO	.002				
RO	.448				

Physical properties, determined by Chester R. Austin,
Properties in green state

Workability: This material is rather plastic. A good column is extruded from the die.

Time of slaking: 14.90 minutes.

Water of plasticity: 22.14 per cent.

Dry shrinkage:

Volume: 15.40 per cent.

Linear: 4.99 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 345 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	25.26	11.92	6.0	12.95	1.95	2.60
04	13.63	20.01	6.3	6.23	2.20	2.52
02	13.13	21.42	6.7	5.92	2.23	2.55
1	10.37	23.35	7.3	4.57	2.27	2.53
3	6.24	24.70	7.6	2.68	2.32	2.47
5	2.99	24.93	7.7	1.27	2.34	2.40
7	2.24	25.20	7.8	0.97	2.31	2.35

Fired modulus of rupture:
Cone 05, 2,943 pounds per square inch.
Cone 4, 4,148 pounds per square inch.

Fired specific impact strength:
Cone 05, 1.37 centimeter kilograms per square centimeter.
Cone 4, 1.09 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 4, 3,233 pounds per square inch.

Best firing range: Cone 06 to cone 5.

Overfiring temperature: Cone 9.

Pyrometric cone equivalent: Cone 16.

Scumming: Scum occurs on all trials fired to cone 5 and lower but scum is not apparent on trials fired above cone 5. Five pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The color of the salt glaze produced at 2,050°F. is a light brown with brownish green and yellowish green mottlings. When the $BaCO_3$ is added the color of the glaze produced at 2,100°F. is a chocolate brown.

Utilization: This shale was being used for the production of sewer pipe. The physical properties of the material suggest that it can be used also for the production of drain tile, face brick, and common brick. On firing the material develops a good red color at cone 1.

Vinton County. Bodies of sandy shale are found on the Strasburg horizon in practically every township in Vinton County where it outcrops, including Brown, Madison, Vinton, Clinton, Wilkesville, Swan, Elk, and Knox townships. In Elk and Swan townships the outcrops occur over small areas as they are confined to the crests of the high hills and ridges, but in Brown, Madison, Vinton, and Wilkesville townships the exposures are present at lower levels and have a greater areal extent. The average interval from the Lower Kittanning coal to Middle Kittanning clay in Vinton County is about 36 feet.

The Oak Hill clay is generally present except where replaced by massive sandstone. It is separated from the Lower Kittanning coal by a shale interval which averages about 7 feet in thickness. Near Hope Furnace in Brown Township the Oak Hill clay is overlain by a 20-foot bed of sandy shale. In Section 23, Swan Township, the material is also a sandy shale with a thickness of about 20 feet. In Section 30, Madison Township, the intervals from Oak Hill clay to the Lower Kittanning coal and to the Upper Kittanning clay are made up of sandy shale. The following measurements from the southern part of Section 29, Wilkesville

Township, illustrate the general stratigraphic relations and the changeable character of the Strasburg member:[1]

		Ft.	In.
Coal blossom, *Middle Kittanning*		1	0
Clay and shale		3	0
Sandstone, shaly	*Strasburg*	5	0
Shale, siliceous	*Strasburg*	7	0
Shale and covered	*Strasburg*	20	0
Sandstone, shaly	*Strasburg*	8	0
Shale, gray	*Strasburg*	..	11
Shale, soft	*Strasburg*	..	3
Coal, bony	*Lower Kittanning*	1	6
Clay, impure	*Lower Kittanning*	..	2
Coal, good	*Lower Kittanning*	1	8
Clay, impure	*Lower Kittanning*	..	2
Coal, good	*Lower Kittanning*	..	5

Hocking County. In Hocking County the outcrops of the Strasburg horizon extend through Starr, Green, Ward, and Falls Gore townships. Measured sections of the member show thicknesses ranging from 15 to 35 feet. In places massive sandstone occupies the entire interval between the Lower Kittanning coal and the Middle Kittanning clay, as in sections 6 and 12, Green Township. At other places the Oak Hill clay appears in this interval and is overlain and underlain with sandy shale and shaly sandstone. Such occurrences are found in Section 36, Ward Township, and in Sections 23 and 35, Starr Township. The following record was made by Wilber Stout along the road north of Paine Crossing in Section 36, Ward Township:

		Ft.	In.
Coal blossom, *Middle Kittanning*		5	0
Clay		1	0
Sandstone, shaly		4	0
Clay, dark, coaly, *Strasburg* horizon		..	3
Clay, light to dark, shaly	*Oak Hill*	11	9
Clay, dark, carbonaceous	*Oak Hill*	2	0
Shale		4	0
Coal blossom, *Lower Kittanning*		1	0
Clay, light, plastic		5	0

Shale from the Strasburg horizon has not been utilized for ceramic products in Hocking County.

Athens County. The area in Athens County where the Strasburg member lies above drainage is small as exposures are confined to the valleys of Hewitt Fork in Waterloo Township and of the Hocking River in York Township. Strasburg shale has been used to a limited extent in mixtures with the Lower Kittanning clay by the Nelsonville Brick Co. at Nelsonville. In Waterloo Township the member consists of both

[1] Geol. Survey Ohio, 4th Ser., Bull. 31, p. 300, 1927.

sandstone and sandy shale as shown in the following section reported by Wilber Stout from the Baltimore and Ohio Railway cut in Section 32:

		Ft.	In.
Coal, bony	Middle Kittanning	..	7
Clay parting	Middle Kittanning	..	3
Coal	*Middle Kittanning*	1	11
Shale parting	Middle Kittanning	..	1½
Coal	Middle Kittanning	1	0
Clay, siliceous		2	0
Shale and shaly sandstone		19	0
Clay, light, plastic		5	0
Sandstone, shaly		14	0
Shale, dark		..	6
Coal, *Lower Kittanning*		..	11
Clay, light, plastic		4	0

Perry County. From Hocking County the belt of outcrops of the Strasburg shale horizon passes north through the east central part of Perry County where exposures are found in Coal, Salt Lick, Monday Creek, Jackson, Pike, Clayton, Harrison, and Madison townships. The member is of little value in this county as the Oak Hill clay is generally present with a thickness of 5 feet or more and as the Middle Kittanning coal usually lies close above it.

Muskingum County. The belt of outcrops of the Strasburg shale covers much of the western half of Muskingum County for exposures occur in part or all of Newton, Clay, Brush Creek, Hopewell, Wayne, Falls, Springfield, Washington, Muskingum, Cass, Madison, Adams, and Monroe townships. The interval from the Lower Kittanning coal to the Middle Kittanning clay in this county ranges from about 12 to 50 feet, but averages less than 25 feet. The shale and shaly sandstone which compose this interval are further reduced in thickness by the presence of the Oak Hill clay which is widely distributed over the area but which is rather irregular in its occurrence. Good bodies of shale are found on the Strasburg horizon, however, in parts of Hopewell, Muskingum, Cass, and Madison townships. In Section 3, Muskingum Township, the sandy shale on this horizon has a thickness of about 35 feet. In Section 11 Springfield Township, the material is a sandy shale with a thickness of about 20 feet. The following record was measured by Wilber Stout in the northeast part of Section 19, and the southwest part of Section 11, Hopewell Township:

		Ft.	In.
Coal blossom, *Middle Kittanning*		3	0
Shale, *Strasburg*		20	0
Clay, flint and plastic	*Oak Hill*	3	0
Clay, light	Oak Hill	3	0
Shale with iron ore		1	0
Shale, soft		5	0
Limestone, fossiliferous, *Hamden*		..	6
Clay and covered, *Lower Kittanning*		8	0

Shale from the Strasburg horizon has been used to a limited extent at the plant of the Ohio Welfare Department at Roseville, Clay Township. The following measurements from the pit are representative for the outcrops in the southern part of Muskingum County[1]

		Ft.	In.
Coal, *Middle Kittanning*		3	6
Clay, *Middle Kittanning*		..	10
Shale, *Strasburg*		4	10
Clay, light, plastic	*Oak Hill*	3	0
Clay, semi-flint	*Oak Hill*	3	2
Clay, flint, ferruginous	*Oak Hill*	2	6
Clay, gray, plastic	*Lower Kittanning*	2	8
Clay, white, plastic	*Lower Kittanning*	2	9

Coshocton County. The area of exposures of the Strasburg shale horizon in Coshocton County is large as outcrops are due above drainage in parts of every township with the possible exception of Tiverton and Newcastle in the northwestern part. In the townships lying west of the Muskingum River and Killbuck Creek, the area of the member is small as exposures occur near the hilltops. The Oak Hill clay is generally present close above the Lower Kittanning horizon in that portion of the county lying west of the Muskingum and south of the Walhonding rivers. Shale and shaly sandstone having an average thickness of about 25 feet comprise the type of rock generally found between the Lower Kittanning coal and Middle Kittanning clay at other places in the county. The general relations of the beds are shown in the following record, secured by Wilber Stout in Section 25, Washington Township:

	Ft.	In.
Coal blossom, *Middle Kittanning*	1	0
Covered interval	10	0
Shale	8	0
Clay, light, *Oak Hill*	3	0
Shale and covered	6	0
Clay, light, *Lower Kittanning*	3	0

Good exposures of the Strasburg shale are found at the pit of the Coshocton Brick Co. at Coshocton. Here the Lower Kittanning clay was formerly used to produce a buff face brick, the Strasburg shale for a red face brick, and the Middle Kittanning shale for paving block. The Clarion clay was being used in the plant in 1929. A measurement of the exposures in the pit is as follows:

		Ft.	In.
Shale, sandy, estimated thickness		35	0
Coal blossom, *Middle Kittanning*		1	0
Clay, light	*Middle Kittanning*	5	0
Clay, yellowish gray, sandy	*Middle Kittanning*	11	9

[1] Birch, R. E., and Austin, C. R., Ceramic Materials at Roseville State Brick Plant, Opp. p. 7, 1919.

		Ft.	In.
Shale, soft	Strasburg	5	6
Sandstone, fine grained	Strasburg	3	0
Shale, gray, sandy	Strasburg	15	0
Bottom of pit			
Shale, gray, a little sandy	Strasburg	3	0
Shale, black, carbonaceous	Strasburg	2	0
Coal, *Lower Kittanning*		2	6
Clay, gray, plastic		10	6

A sample of Strasburg shale was cut from the exposures at the above location on August 6, 1929. The sample included the 15-foot bed of sandy shale forming the lowest exposures in the pit and the 5-foot 6-inch bed underlying the Middle Kittanning clay. The intervening 3 feet of sandstone was not included in the sample. The results of the tests for which the sample was submitted are given below:

Sample No. 28

Tests of Strasburg shale from pit of the Coshocton Brick Company, Coshocton, Coshocton County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.24
Water, combined, H_2O+	6.08
Silica, SiO_2	62.10
Alumina, Al_2O_3	18.43
Titanic oxide, TiO_2	1.27
Phosphorus pentoxide, P_2O_5	0.14
Ferric oxide, Fe_2O_3	5.15
Ferrous oxide, FeO	0.81
Lime, CaO	0.60
Magnesia, MgO	0.65
Sodium oxide, Na_2O	0.30
Potassium oxide, K_2O	2.69
Manganese oxide, MnO	0.05
Sulphur, S	0.04
Carbon dioxide, CO_2	none
Carbon, organic, C	0.50

Oxide ratio

$$\left.\begin{matrix} K_2O & .146 \\ Na_2O & .016 \\ CaO & .033 \\ MgO & .035 \\ FeO & .295 \\ MnO & .003 \end{matrix}\right\} Al_2O_3 \quad 1.00 \left\{\begin{matrix} SiO_2 & 3.369 \\ TiO_2 & 0.069 \\ P_2O_5 & 0.008 \end{matrix}\right.$$

RO .528

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has good plasticity. A good column is extruded from the die.

Time of slaking: 31.25 minutes.

Water of plasticity: 20.83 per cent.

Dry shrinkage:

Volume: 13.58 per cent.

Linear: 4.34 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 505 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	24.63	9.91	3.2	12.30	1.99	2.64
04	19.38	13.06	4.2	9.37	2.07	2.55
02	15.51	17.50	5.5	7.40	2.11	2.49
1	13.19	20.16	6.3	6.09	2.17	2.50
3	12.40	21.03	6.6	5.46	2.27	2.59
5	7.61	22.36	6.9	3.30	2.30	2.50
7	6.67	22.54	7.0	2.88	2.32	2.48
8	6.20	22.63	7.0	2.67	2.32	2.47

Fired modulus of rupture:
Cone 02, 3,141 pounds per square inch.
Cone 5, 3,860 pounds per square inch.

Fired specific impact strength:
Cone 03, 1.46 centimeter kilograms per square centimeter.
Cone 4, 1.28 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 5, 11,429 pounds per square inch.

Best firing range: Cont 06 to cone 5.

Overfiring temperature: Cone 9.

Pyrometric cone equivalent: Cone 16.

Scumming: Scum occurs on all trials fired to cone 3 and lower but scum is not apparent on trials fired above cone 3. Two pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The color of the salt glaze produced at 2,100°F. is a brownish green and pinkish gray grading into reddish brown. The glaze produced at 2,050°F. is brown with some green intermingled. When $BaCO_3$ is added the color of the glaze produced at 2,100°F. is a light chocolate brown.

Utilization: This shale was being used for the production of face brick. It is adapted to the production of common brick and because of its good working properties, it can probably be utilized for the production of hollow tile, drain tile, and possibly for sewer pipe. The fired material develops a good red color at cone 1.

Guernsey County. Outcrops of the Strasburg member in Guernsey County are small in extent as they are limited to the valleys of Wills Creek in Wheeling Township, Indian Camp Run in Knox Township, and Wills Creek and its tributaries in Liberty Township. In this area the interval from the Lower Kittanning coal to the Middle Kittanning clay is composed chiefly of shale and related types as the Oak Hill clay and Strasburg coal are generally wanting. The thickness ranges between 25 and 45 feet. No attempt has been made to utilize the material from the Strasburg horizon in this county.

Holmes County. The Strasburg member is above drainage in part or all of Paint, Salt Creek, Prairie, Knox, Monroe, Hardy, Berlin, Walnut Creek, Clark, Mechanic, and Killbuck townships. This horizon presents few possibilities in the county as sandstone is more or less well developed throughout the entire area of outcrop. Where the sandstone is thin and poorly expressed the Middle Kittanning coal is generally overlain with beds of calcareous shale representing the Hamden member, above which are shales with many iron ore nodules. The average thickness of the Strasburg interval varies from 18 to 80 feet in this county but averages about 40 feet. In the southwestern corner of Section 19, Walnut Creek Township, Lower Kittanning coal is overlain with 27 feet of shale which is rich in iron ore concretions. In the southeastern corner of Berlin Township the Lower Kittanning coal is overlain by sandstone, above which is several feet of sandy ferruginous shale. In the following section of exposures in the southeast corner of Paint Township near Easley School, the Strasburg member is composed of shale with the character and thickness as given below.[1]

		Ft.	In.
Coal, *Middle Kittanning*		..	6
Shale, siliceous to clay-like, *Strasburg*		31	0
Shale, dark, carbonaceous, fossiliferous, some fossils are pyrite, *Hamden* horizon		2	0
Shale, coaly	*Lower Kittanning*	..	2
Coal, good	*Lower Kittanning*	1	10
Pyrite, not continuous	*Lower Kittanning*	..	½
Coal, good	*Lower Kittanning*	..	9

Tuscarawas County. The Strasburg member is an economic resource of much value in Tuscarawas County as bodies of shale on this horizon suitable to the manufacture of brick and tile outcrop in every township in the county with the possible exception of Perry in the southeast corner. Throughout the southern part of the county the shale deposits extend to the top of the Lower Kittanning coal as the Oak Hill clay and Hamden limestone are generally wanting. In the northern part of the county the Strasburg shale member is broken near the middle by a coal and clay which are considered here as the equivalent of the Oak Hill clay and the Strasburg coal. The thickness of the Strasburg member in this county varies from 10 to 50 feet, but averages slightly more than 30 feet. Due to the valuable deposits of Lower Kittanning clay, which has absorbed the interest of the ceramic industries in this county, very little attention has been given to the overlying shale deposits.

In the western and northwestern parts the outcrops of Strasburg shale occur at higher elevations than prevail in the eastern and southeastern portions of the county as the general inclination of the beds is in a southeast direction. At the plant of the Belden Brick Company located in western Clay Township, the Strasburg is composed of shale having a thickness of 34 feet. The thickness is much the same at the plant of the Wolf-Lanning Clay Company at Dennison. Exposures at the plant of the Belden Brick Company at Uhrichsville are reported as follows:[2]

[1] Section from unpublished manuscript on Holmes County by Dr. George White.
[2] Geol. Survey Ohio, 4th Ser., Bull. 26, p. 309, 1923.

		Ft.	In.
Shale		15	0
Coal, shaly and dark shale		..	6
Coal	*Lower Kittanning*	2	1
Parting		..	1
Coal		1	11
Clay, light to dark, plastic		6	6
Ore		..	4
Shale, *Strasburg*		11	8
Coal, *Lower Kittanning*		1	6
Clay, plastic, upper part dark		6	0
Clay, light, siliceous		4	6
Clay, siliceous, ferruginous		2	0

At the plant of the Zoar Fire Clay Company at Zoar the Lower Kittanning clay is overlain by shale having a thickness of about 16 feet. Much the same condition exists at the workings of the Federal Clay Products Company at Mineral City and at the National Fire Brick Company at Strasburg. The following section is from the pit of the Columbia Fire Brick Company at Strasburg, Franklin Township:

		Ft.	In.
Coal, *Strasburg*		1	8
Clay, impure, dark, *Oak Hill*		1	8
Shale		18	0
Coal, *Lower Kittanning*		2	8
Clay, plastic, average thickness		4	0
Clay, flint, average thickness	*Lower Kittanning*	3	0
Clay, plastic, irregular		3	0

The Strasburg shale has not been utilized for brick or tile production in Tuscarawas County.

Carroll County. The Strasburg member is above drainage in the western and northwestern parts of Rose Township and along Sandy Creek in Brown Township. The material is predominantly shale. It is being utilized to some extent in conjunction with the Lower and Middle Kittanning clays by the National Fireproofing Company in Section 29, Rose Township. A section of this exposure at the plant as described by Wilber Stout is as follows:

		Ft.	In.
Coal, *Middle Kittanning*		3	6
Clay, upper part dark		4	0
Shale, gray	*Strasburg*	20	0
Shale, dark		7	0
Coal, *Lower Kittanning*		2	9
Clay, plastic		2	8
Clay, flint		3	6
Clay, plastic, lower part siliceous		7	4

Stark County. The Strasburg shale has been utilized to some extent in Stark County where the area of exposures includes parts of Pike, Sandy, Osnaburg, Paris, Nimishillen, Washington, and Lexington townships. The thickness of the bed varies from about 15 to 30 feet. Both the Lower and Middle Kittanning clays are used at plants Nos. 1 and 2 of the Whitacre-Greer Fireproofing Company at Waynesburg, Sandy Township, where the following section showing the Strasburg shale was secured by Wilber Stout:

		Ft.	In.
Coal, *Middle Kittanning*		2	8
Clay, dark	*Middle Kittanning*	1	0
Clay, light		5	0
Clay, light, ferruginous		1	0
Clay, dark		2	0
Shale, sandstone and covered, *Strasburg*		27	0
Limestone, fossiliferous, *Hamden*		1	0
Coal, *Lower Kittanning*		2	6
Clay, light, plastic, *Lower Kittanning*		5	0

Shale from the Strasburg horizon is utilized to a limited extent as raw material for the production of a red face brick at the plant of the Mapleton Clay Products Company located in Section 23, Osnaburg Township. Both the Lower and Middle Kittanning clays and the Middle Kittanning shale are also used to produce a greater variety in colors and shades of brick. A section of the rock exposures in the pit is as given below:

		Ft.	In.
Drift		6	0
Shale, bluish gray, sandy and micaceous at top		23	0
Shale, bluish gray, with ironstone concretions		3	6
Coal, bony	*Middle Kittanning*	..	2
Coal, good		2	4
Clay, bluish gray, siliceous, *Middle Kittanning*		8	8
Shale, gray, sandy, *Strasburg*		21	0
Coal, *Lower Kittanning*		2	8
Clay, gray, plastic	*Lower Kittanning*	5	0
Clay, gray, siliceous		10	6

The Canton Brick and Fireproofing Company utilizes Strasburg shale in the Robertsville plant located in Section 19, Paris Township. Shale from this member is also used for common brick at the plant of the Stark Brick Company near East Canton in Section 18, Osnaburg Township. Mixtures of this shale and Middle Kittanning clay are utilized for salt glazed brick, which is the chief product of the plant. A description of the rock exposures as recorded by Wilber Stout is as follows:

	Ft.	In.
Shale	5	0
Coal, *Middle Kittanning*	3	9
Clay, *Middle Kittanning*	7	6
Shale	3	0
Coal, bony, *Strasburg*	..	10

		Ft.	In.
Shale, dark		8	0
Shale, with ironstone concretions		..	6
Coal, *Lower Kittanning*		2	4
Clay, plastic	*Lower Kittanning*	4	6
Clay, light, siliceous	*Lower Kittanning*	7	6

A small amount of Strasburg shale has been dug from the pit of the Alliance Clay Products Company, which is located in Alliance at the eastern edge of Lexington Township. As the plant is situated across the line in Mahoning County a detailed account of the deposits will be considered under that county.

Mahoning County. The horizon of the Strasburg shale extends through the southern part of Mahoning County, including parts of Smith, Goshen, Green, Canfield, Beaver, Springfield, and Poland townships. As this area is covered with glacial drift, few rock exposures occur and little is known about the member except where the material has been worked for ceramic purposes. Strasburg shale has been utilized to a small extent by the Alliance Clay Products Company at Alliance. The plant is situated at the west edge of Section 31, Smith Township, but the pit from which the material is secured is in Section 36, Lexington Township, Stark County. A description of the exposures of Strasburg shale is given below:

		Ft.	In.
Coal, *Middle Kittanning*		2	6
Clay, bluish gray, siliceous, *Middle Kittanning*		14	0
Shale, bluish gray, sandy	*Strasburg*	7	3
Sandstone	*Strasburg*	1	0
Shale, bluish gray	*Strasburg*	6	6

The Middle Kittanning clay and Middle Kittanning shale are the chief sources of material. A sample of Strasburg shale as described in the section above was cut on September 7, 1929, and submitted for testing.

Sample No. 25

Tests of Strasburg shale from pit of the Alliance Clay Products Company, Alliance, Mahoning County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.50
Water, combined, H_2O+	6.50
Silica, SiO_2	50.90
Alumina, Al_2O_3	18.81
Titanic oxide, TiO_2	0.96
Phosphorus pentoxide, P_2O_5	0.33
Ferric oxide, Fe_2O_3	0.28
Ferrous oxide, FeO	9.10
Lime, CaO	1.65
Magnesia, MgO	1.10
Sodium oxide, Na_2O	0.11

Oxide ratio

K_2O	.117	Al_2O_3	1.00	SiO_2	2.706
Na_2O	.006			TiO_2	0.051
CaO	.087			P_2O_5	0.017
MgO	.058				
FeO	.497				
MnO	.006				
RO	.771				

Chemical analysis

Potassium oxide, K_2O	2.20
Manganese oxide, MnO ...	0.11
Sulphur, S	0.02
Carbon dioxide, CO_2	6.60
Carbon, organic, C	trace

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This shale has short plasticity. A badly featheredged column is extruded from the die.

Time of slaking: 21.22 minutes.

Water of plasticity: 17.11 per cent.

Dry shrinkage:

Volume: 13.44 per cent.

Linear: 4.29 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 267 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	19.32	12.47	4.0	9.06	2.13	2.64
04	14.08	16.64	5.2	6.36	2.23	2.59
02	14.62	17.38	5.5	6.53	2.28	2.63
1	12.93	19.20	6.0	5.65	2.30	2.63
3	9.64	20.71	6.5	4.12	2.33	2.59
5	6.97	20.84	6.5	2.96	2.35	2.53
7	6.23	17.67	5.6	2.74	2.27	2.43

Fired modulus of rupture:

Cone 05, 2,564 pounds per square inch.

Cone 5, 2,995 pounds per square inch.

Fired specific impact strength:

Cone 05, 1.75 centimeter kilograms per square centimeter.

Cone 4, 1.28 centimeter kilograms per square centimeter.

Fired crushing strength:

Cone 5, 9,679 pounds per square inch.

Best firing range: Cone 08 to cone 5.

Overfiring temperature: Cone 7.

Pyrometric cone equivalent: Cone 11-12.

Scumming: Scum occurs on all trials fired to cone 1 and lower but scum is not apparent on trials fired above cone 1. One pound $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The salt glaze developed at 2,050°F. and at 2,100°F. has a reddish brown color with some gray green and yellow green mottlings. When $BaCO_3$ is added no glaze is produced at 2,100°F.

Utilization: This shale was being blended with the shale overlying the Middle Kittanning coal and the mixture used for the production of face brick. This material can be used also for the production of face brick. On firing a dark reddish brown color is produced.

Strasburg shale supplies some material for the production of face brick at Plant No. 1 of the Alliance Brick Company in Section 29, Smith Township. In addition to shale the Middle Kittanning clay is also utilized. Both materials are worked by open pit methods. The following is a record of the exposures as recorded by Wilber Stout:

	Ft.	In.
Shale, siliceous, and shaly sandstone	20	0
Shale, gray, soft	4	0
Coal, *Middle Kittanning*	3	1
Clay, light to dark, plastic } *Middle Kittanning*	7	0
Clay, siliceous, ferruginous } *Middle Kittanning*	3	0
Shale, bluish gray, argillaceous, *Strasburg*	19	0

The Strasburg shale has not been utilized for the production of ceramic products in Mahoning County outside of Smith Township, and due to the lack of exposures very little is known about the character of the member elsewhere in the county.

Columbiana County. Exposures of the Strasburg shale in Columbiana County are confined to the valleys of the Little Beaver River and its tributaries in northern and eastern St. Clair, eastern Middleton, Elk Run, northern Madison, northern Center, and northern Salem townships; along the headwaters of the Mahoning River in northern Knox Township; along the Ohio River in southern Liverpool and eastern Yellow Creek townships; and along Yellow Creek in southwestern Yellow Creek Township. The member in this county consists of dark sandy shale with many concretionary masses of iron carbonate. The average thickness for the county is about 17 feet. In Section 28, Salem Township, the material is a dark shale with ore nodules with a total thickness of about 40 feet. Much the same conditions prevail near Lisbon in Center Township and along the valley of Middle Fork in Elk Run Township. A section of the rock exposures near the mouth of Little Beaver River as described by Wilber Stout is given below:

	Ft.	In.
Shale	15	0
Coal, *Middle Kittanning*	1	10
Clay, plastic, with concretions, *Middle Kittanning*	5	0
Shale, dark, with concretions, *Strasburg*	16	0
Coal, *Lower Kittanning*	2	6
Clay, part siliceous, *Lower Kittanning*	8	0

Throughout the western part of Liverpool and the northeastern part of Yellow Creek townships sandstone is prominently developed on the Strasburg horizon. Shale again appears near Wellsville and is likewise present with normal thickness along Yellow Creek in southwestern Yellow Creek Township. Strasburg shale has not been utilized in Columbiana County for ceramic products.

Jefferson County. In Jefferson County the Strasburg horizon is above drainage along Yellow Creek in Saline Township and along the Ohio River in Saline and Knox townships. The Middle Kittanning coal and clay, which mark the upper limit of this member, are generally present in Saline Township and extend along the Ohio River Valley as far south as Empire. South of Empire the coal is either represented by black shale or its horizon is unmarked. In the Yellow Creek Valley the Strasburg member is composed of dark sandy shale with ore nodules embedded in it. The following section secured near Irondale in the southern part of Section 26 is representative:

	Ft.	In.
Coal, *Middle Kittanning*	2	4
Clay, siliceous, ferruginous, *Middle Kittanning*	7	2
Shale, gray, siliceous, with ore nodules, *Strasburg*	16	6
Coal, bony } *Lower Kittanning*	..	2
Coal, good } *Lower Kittanning*	2	10
Clay, plastic, light to dark, *Lower Kittanning*	4	2

Shale is present on the Strasburg horizon along the eastern edge of Saline Township as far south as Port Homer. At Ekeyville in the northeastern corner of Knox Township this member is represented by massive sandstones. The Strasburg shale has not been utilized for ceramic purposes in Jefferson County.

Lower Freeport Shale

The stratigraphic position of the Lower Freeport shale is between the Lower Freeport clay and Middle Kittanning coal. In various parts of the State this interval includes in addition such local members as the Washingtonville shale, the Upper Kittanning coal and clay, and the more widely distributed Lower Freeport sandstone. The Washingtonville member is found chiefly in Columbiana County where it is a thin bed of black carbonaceous shale ranging in thickness from 1 foot 6 inches to 3 feet, and lying on an average about 4 feet above the Middle Kittanning coal. Overlying the Middle Kittanning coal in parts of Columbiana County at intervals ranging from 12 to 23 feet, there is a thin bed of coal which is correlated with the Upper Kittanning of Pennsylvania. As this bed is always thin and patchy in distribution its presence is of little detriment to the Lower Freeport shale.

Of wider extent in Ohio than either the Washingtonville or Upper Kittanning members is the Lower Freeport sandstone which normally lies close below the Lower Freeport coal. This sandstone partially or completely replaces the Lower Freeport shale and in some localities extends downward to the Lower Kittanning coal. Where this sandstone is wanting, shale of a bluish gray sandy type takes its place. Lower Freeport shale is widely distributed in Ohio for it outcrops over a belt extending from Mahoning, Columbiana, and Jefferson counties on the east to Lawrence

County on the south. The thickness varies within wide limits but averages about 36 feet for the outcrops as a whole. Bodies of shale suitable for the fabrication of brick and tile products are widely distributed on this outcrop as the material has been utilized successfully in Hocking, Muskingum, Coshocton, Tuscarawas, Carroll, Stark, and Mahoning counties. Throughout the southern part of the belt of outcrops, including portions of Vinton, Athens, Jackson, Gallia, and Lawrence counties, sandstone is prominently developed on the Lower Freeport horizon and in places it has entirely replaced the corresponding shale facies. The Lower Freeport ranks second in Ohio as a source of shale material for the manufacture of ceramic products.

Lawrence County. The horizon of the Lower Freeport shale outcrops over a north and south belt extending through the central part of Lawrence County and including parts of Perry, Upper, Lawrence, Elizabeth, Decatur, Washington, Aid, and Symmes townships. The thickness of the horizon varies from about 30 to 50 feet, but averages about 40 feet. In general the horizon in this county is represented by massive sandstone, but in places this sandstone thins or even disappears and its place is taken by sandy shale. Thus north of Dean at the tunnel on the Cincinnati, Hamilton and Dayton Railroad the Lower Freeport has a thickness of about 33 feet, more than half of which is a sandy shale. Much the same condition exists near Waterloo in Symmes Township. Near Kitts Hill in the western part of Lawrence Township, this horizon is composed entirely of massive sandstone. Wilber Stout reports the following section near Center Station, Aid Township:

	Ft.	In.
Coal blossom, *Lower Freeport*	1	0
Clay	2	0
Shale, gray	22	0
Sandstone, nodular	2	0
Shale, sandy	7	0
Sandstone, medium bedded	14	0
Shales and covered	2	0
Sandstone	1	0
Coal blossom, *Middle Kittanning*	1	0

Gallia County. In Gallia County the outcrops of the Lower Freeport shale and sandstone horizon are limited to the western edge including parts of Greenfield, Walnut, Perry, Raccoon, and Huntington townships. Here the average thickness is about 24 feet. Much sandstone is present on this horizon in the county as illustrated by the following measurements near McDaniel in Section 1, Walnut Township:[1]

[1] Geol. Survey Ohio, 4th Ser., Bull. 20, p. 639, 1916.

	Ft.	In.
Coal, Lower Freeport	..	8
Shale, soft	2	0
Shale and shaly sandstone	18	0
Sandstone and covered	17	0
Coal, *Middle Kittanning*	3	6

Jackson, Vinton, and Athens Counties. The Lower Freeport member is of little value as a source of ceramic materials in Jackson County, where outcrops are found in Madison, Bloomfield, and Milton townships, as sandstone is prominently developed on this horizon throughout the area. Much the same condition prevails in Vinton County. Massive sandstone belonging to the Lower Freeport member persists along the eastern border of the county in Wilkesville, Vinton, Madison, Brown, and Knox townships and at some localities reaches a thickness of as much as 50 feet. In Athens County this horizon is above drainage along Hewitt Fork in Waterloo Township and along the Hocking Valley in York Township. In both of these localities sandstone is prominently developed on the Lower Freeport horizon. The following section at Plant No. 1 of Nelsonville Brick Company shows this general relation:

		Ft.	In.
Coal, *Lower Freeport*		..	4
Clay, gray, with ore and limestone nodules		6	6
Shale, greenish gray, sandy, ferruginous at top		3	6
Shale, sandstone and covered		28	6
Sandstone, massive, coarse-grained		10	0
Shale with thin coal bands	*Middle Kittanning*	1	6
Shale, soft	*Middle Kittanning*	..	4
Coal	*Middle Kittanning*	2	11
Parting	*Middle Kittanning*	..	½
Cave	*Middle Kittanning*	..	3
Parting	*Middle Kittanning*	..	½
Coal	*Middle Kittanning*	1	5
Clay, bluish gray, siliceous		10	6

Hocking County. In Hocking County the Lower Freeport shale horizon is exposed above drainage in parts of Ward, Falls Gore, Green, and Starr townships. The material consists of sandy shale and sandstone which in measured sections varies from 14 to 25 feet in thickness. The following section was secured by Wilber Stout about 1¼ miles north of Starr, Starr Township, Hocking County:

		Ft.	In.
Clay, dark, with limestone and ore nodules	*Lower Freeport*	5	0
Limestone	*Lower Freeport*	1	0
Clay, shaly, dark gray	*Lower Freeport*	2	0
Shale and covered, *Lower Freeport*		21	0
Coal blossom, *Middle Kittanning*		2	0

The Lower Freeport shale has been used as a source of material for face brick for a number of years by the Greendale Brick Company located at Greendale in Green Township. Lower Kittanning clay is also used for the light shades of brick. Both producer gas and coal are used for fuel. The exposures in the pit located in the east central part of Section 6 are as described below:

		Ft.	In.
Smut, *Lower Freeport* coal horizon		..	3
Clay, yellowish, with limestone and iron ore nodules	*Lower Freeport*	8	6
Clay, light, arenaceous, with nodules of limestone	*Lower Freeport*	2	0
Shale, bluish gray to greenish gray, sandy, micaceous		25	0
Base of pit			
Covered interval		3	0
Shale, black		1	0
Coal, *Middle Kittanning*		6	6

On July 18, 1929, a sample for testing was taken from the 25-foot bed of shale exposed in the pit. The results of the tests are stated below:

Sample No. 32

Tests of Lower Freeport shale from the pit of Greendale Brick Company, Greendale, Hocking County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.10
Water, combined, H_2O+	5.59
Silica, SiO_2	58.21
Alumina, Al_2O_3	20.17
Titanic oxide, TiO_2	1.27
Phosphorus pentoxide, P_2O_5	0.18
Ferric oxide, Fe_2O_3	5.29
Ferrous oxide, FeO	1.42
Lime, CaO	1.12
Magnesia, MgO	1.78
Sodium oxide, Na_2O	0.22
Potassium oxide, K_2O	2.88
Manganese oxide, MnO	0.08
Sulphur trioxide, SO_3	0.18
Carbon dioxide, CO_2	0.51
Carbon, organic, C	0.15

Oxide ratio

K_2O	.143	Al_2O_3	1.00	SiO_2	2.886
Na_2O	.011			TiO_2	0.063
CaO	.055			P_2O_5	0.009
MgO	.088				
FeO	.306				
MnO	.004				
RO	.607				

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has short plasticity. A badly featheredged column is extruded from the die.

Time of slaking: 15.78 minutes.

Water of plasticity: 19.31 per cent.

Dry shrinkage:

Volume: 8.96 per cent.

Linear: 2.90 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 193 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	26.03	10.73	3.5	13.05	1.99	2.70
04	17.08	18.29	5.8	7.93	2.16	2.60
02	15.16	19.60	6.2	6.90	2.14	2.58
1	11.86	22.29	7.0	5.24	2.13	2.57
3	7.82	24.31	7.5	3.35	2.13	2.54
5	4.44	24.31	7.5	1.86	2.37	2.49
7	3.54	23.40	7.3	1.53	2.33	2.41

Fired modulus of rupture:

Cone 04, 2,091 pounds per square inch.

Cone 5, 3,543 pounds per square inch.

Fired specific impact strength:

Cone 05, 1.41 centimeter kilograms per square centimeter.

Cone 4, 1.26 centimeter kilograms per square centimeter.

Fired crushing strength:

Cone 5, 16,127 pounds per square inch.

Best firing range: Cone 06 to cone 5.

Overfiring temperature: Cone 7.

Pyrometric cone equivalent: Cone 14.

Scumming: Scum occurs on all trials fired to cone 2 and lower but scum is not apparent on trials fired above cone 2. Two pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The color of the salt glaze produced at 2,100°F. is a reddish brown gray mottle with some yellow green colorations while that produced at 2,050°F. is more brownish with a little orange mottling. Some pimpling is apparent on the glaze produced at 2,050°F. When $BaCO_3$ is added the glaze produced at 2,100°F. has a chocolate brown color.

Utilization: This shale was being used for the production of face brick. It can be used also for the production of common brick. The fired material has a stony structure. A good red color is developed at cone 01.

Perry County. From northwestern Athens and eastern Hocking counties the belt of outcrops of the Lower Freeport shale horizon extends north through eastern Perry County, where the member outcrops in Monday Creek, Salt Lick, Monroe, Jackson, Pike, Pleasant, Bearfield, Clayton, Madison, and Harrison townships. Much the same conditions occur here as are found in Hocking and Athens counties as the member is variable in thickness and as it consists of sandy shale and sandstone which vary in proportions from place to place.

Muskingum County. In Muskingum County the Lower Freeport horizon appears at the surface in parts of Clay, Newton, Brush Creek, Harrison, Hopewell, Springfield, Wayne, Falls, Muskingum, Washington, Cass, Madison, Salem, Adams, and Monroe townships. Throughout the outcrop areas in this county shale is the prevailing type of rock on the Lower Freeport horizon although bodies of sandstone of somewhat local extent are found in every township where exposures occur. The shale is variable in composition, ranging from the soft and carbonaceous varieties to the highly siliceous types. The thickness of the shale ranges from 20 to 50 feet. Material from this horizon has been utilized near Roseville in Clay Township and at Zanesville.

The Lower Freeport shale was formerly utilized to a limited extent by the Roseville Paving Brick Company and the Hydraulic-Press Brick Company located near Roseville. The rock exposures in the pit at the former plant are described as follows:[1]

	Ft.	In.
Sandstone, massive, coarse-grained	5	0
Covered	3	8
Sandstone, thin bedded, shaly	5	6
Shale, light	16	0
Coal, weathered, *Middle Kittanning*	3	3

At the Roseville State Brick Plant the Lower Freeport shale has a thickness of about 24 feet and is fairly uniform throughout the entire bed. Shale belonging to this member was formerly used extensively at Zanesville for the production of paving brick. Plants No. 1 and 2 of the Burton-Townsend Brick Company, now owned by the Zanesville Clay Products Company, utilized this shale for a number of years as did also the Harris Brick Company, which plant has been abandoned. The exposures in and near the pit at Plant No. 2 of the Zanesville Clay Products Company located in the western edge of Section 4, Wayne Township, are described below:

		Ft.	In.
Sandstone, soft, micaceous, shaly		16	0
Top of pit			
Shale, bluish gray, sandy	*Lower Freeport*	19	6
Shale, bluish gray, sandy, with ore nodules	*Lower Freeport*	6	9
Bottom of pit			
Covered		1	9
Coal	*Middle Kittanning*	2	0
Shale, parting	*Middle Kittanning*	..	2
Coal	*Middle Kittanning*	..	10
Clay, bluish, sandy		5	0

The shale exposed in the pit was sampled on July 24, 1929, and the sample was submitted for testing, the results of which are given below:

Sample No. 37

Test of Lower Freeport shale from pit of Plant No. 2, of Zanesville Clay Products Company, Zanesville, Muskingum County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	0.77
Water, combined, H_2O+	6.71
Silica, SiO_2	56.95
Alumina, Al_2O_3	15.08
Titanic oxide, TiO_2	0.96
Phosphorus pentoxide, P_2O_5	0.19
Ferric oxide, Fe_2O_3	4.71
Ferrous oxide, FeO	5.19
Lime, CaO	0.80

Oxide ratio

K_2O	.202	Al_2O_3	1.00	SiO_2	3.776
Na_2O	.037			TiO_2	0.064
CaO	.053			P_2O_5	0.012
MgO	.156				
FeO	.645				
MnO	.005				
RO	1.098				

[1] Geol. Survey Ohio, 4th Ser., Bull. 21, p. 208, 1918.

Magnesia, MgO...........	2.35
Sodium oxide, Na_2O.......	0.56
Potassium oxide K_2O.....	3.04
Manganese oxide, MnO....	0.08
Sulphur trioxide, SO_3......	0.03
Ferrous sulphide, FeS_2.....	0.50
Carbon dioxide, CO_2.......	1.50
Carbon, organic, C........	0.83

Physical properties, determined by Chester R. Austin
Properties in green state

Workability: This material has good plasticity. A good column is extruded from the die.

Time of slaking: 9.48 minutes.

Water of plasticity: 18.09 per cent.

Dry shrinkage:

Volume: 7.73 per cent.

Linear: 2.51 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 202 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	32.43	11.82	3.8	13.40	1.97	2.07
04	22.60	16.09	5.1	10.68	2.11	2.71
02	16.93	19.89	6.2	7.83	2.17	2.61
1	11.86	22.73	7.1	5.29	2.25	2.56
3	8.03	25.18	7.8	3.42	2.33	2.55
5	4.81	28.18	8.6	2.00	2.40	2.54
7	11.28	19.24	6.0	4.17	2.71	3.04

Fired modulus of rupture:

Cone 02, 2,729 pounds per square inch.

Fired specific impact strength:

Cone 03, 1.57 centimeter kilograms per square centimeter.

Cone 5, 1.10 centimeter kilograms per square centimeter.

Fired crushing strength:

Cone 5, 15,839 pounds per square inch.

Best firing range: Cone 06 to cone 5.

Overfiring temperature: Cone 7.

Pyrometric cone equivalent: Cone 9-10.

Scumming: Scum occurs on all trials fired to cone 5 and lower. Five pounds of $BaCO_3$ per ton of material is required to prevent scumming.

Salt glazing: A good salt glaze is produced at both 2,100°F. and at 2,050°F. but the surface shows pimples and warts. The color of the glaze produced at both temperatures is reddish brown with some brown and orange mottling. When $BaCO_3$ is added the glaze formed at 2,100°F. has a chocolate brown color.

Utilization: This shale was being used for the production of paving brick. The physical properties of the shale are such that it can be utilized for face brick and common brick. The fired material has a stony structure. A good red color is developed at cone 1.

Lower Freeport shale is found in varying thickness associated with sandstone deposits north of Zanesville in Muskingum County. Near Hague School in Washington Township the Middle Kittanning coal is overlain by 12 feet of shale above which is massive sandstone. In Section 12, Muskingum Township, the shale has a thickness of 18 feet and in Section 10, Monroe Township, exposures show 15 feet. The following section was secured by Wilber Stout from Section 20, Muskingum Township:

		Ft.	In.
Sandstone and covered		40	0
Shale		20	0
Coal	*Middle Kittanning*	1	11
Parting	*Middle Kittanning*	..	1
Coal	*Middle Kittanning*	1	0

Coshocton County. From Muskingum County the outcrops of the Lower Freeport shale horizon extend north into Coshocton County where the area lies above drainage in all or parts of Linton, Franklin, Virginia, Oxford, Lafayette, Tuscarawas, Jackson, Bedford, Bethlehem, Keene, White Eyes, Adams, Crawford, Mill Creek, and Clark townships.

The horizon is of little ceramic importance in this county as sandstone is prominently developed over the area. In places the sandstone gives way to very sandy shales. Where sandstone is present the base often forms the roof of the Middle Kittanning coal but a common mode of occurrence is to find it separated from the coal by a short shale interval. The following section was secured by Wilber Stout north of Adams Mills in Section 23, Virginia Township:

	Ft.	In.
Sandstone, massive, conglomeratic at base	30	0
Shale	10	0
Coal blossom, Middle Kittanning	3	0
Clay, shale and covered	32	0
Shale	23	0
Limestone, Putnam Hill	3	0

The Coshocton Brick Company has used Lower Freeport shales to some extent for the production of paving block at Coshocton. In addition both Lower Kittanning clay and Strasburg shale are worked for face brick. A measurement of the exposures in the pit is given below:

	Ft.	In.
Shale, sandy, *Lower Freeport*	35	0
Coal blossom, *Middle Kittanning*	1	0
Clay, light, plastic	5	0
Clay, yellowish gray, siliceous	11	9
Shale, gray, soft	5	0
Sandstone, massive, fine-grained	3	0

	Ft.	In.
Shale, gray, sandy	18	0
Shale, black, carbonaceous	2	0
Coal, *Lower Kittanning*	2	6
Clay, gray, plastic	10	6

The Lower Freeport shale has not been utilized at any other place in Coshocton County.

Guernsey County. The distribution of the outcrops of the Lower Freeport shale horizon in Guernsey County is limited to the valley of Wills Creek and its tributaries in Wheeling, Knox, Liberty, and northern Cambridge townships. The member offers few possibilities for ceramic materials in this county as it is composed chiefly of sandstone with minor amounts of highly siliceous shale.

Holmes County. The Lower Freeport is accessible over a large area in Holmes County as the member lies above drainage in all or parts of Paint, Salt Creek, Prairie, Hardy, Berlin, Walnut Creek, Clark, Mechanic, and Killbuck townships. The material consists of massive sandstone and sandy shale, which have added little to the ceramic products of the county as they have been utilized at only one locality. Shale from this horizon together with Middle Kittanning clay were formerly used by the General Clay Products Company at Baltic for making drain tile. As the mixture was too siliceous to yield satisfactory results, the practice was discontinued and Lower Kittanning shale is now utilized. A description of the exposures at the plant which is located in Section 25, Clark Township, is given below:

		Ft.	In.
Shale, gray, sandy	*Lower Freeport*	26	0
Shale, bluish gray, with ore nodules	*Lower Freeport*	8	6
Shale, black, carbonaceous	*Lower Freeport*	2	0
Coal, Middle Kittanning		3	0
Clay, siliceous, ferruginous		5	0
Shale and covered		14	9
Coal, *Lower Kittanning*, not entire thickness		1	0
Covered interval		9	6
Shale, gray, sandy	*Lower Freeport*	19	3
Shale, bluish gray, with some limestone nodules	*Lower Freeport*	4	0

Tuscarawas County. From eastern Holmes and Coshocton and northern Guernsey counties the belt of outcrops of the Lower Freeport shale horizon extends to the east and north into Tuscarawas County where it spreads out over a broad area including parts of every township in the county with the exception of Perry. Shale deposits on the Lower Freeport horizon are widely distributed in the county, but in some localities this material is partially or completely replaced by sandstone. At Newcomerstown in Oxford Township, Lower Freeport shale was formerly utilized for paving brick by the Novelty Brick and Coal Company with fair success. Sandy shale of similar character and varying thickness characterizes the Lower Freeport throughout Salem, Clay, Bucks, and Jefferson townships. In Section 15, Bucks Township, the Middle Kittanning coal is overlain by 15 feet of sandy shale above which is massive sandstone. Shale is generally present on the lower part of the Lower Freeport horizon along the Tuscarawas River Valley in Dover, York, Goshen, Warwick, and Mill townships. The following section was secured by Wilber Stout at the plant of the Belden Brick Company at Uhrichsville.

		Ft.	In.
Sandstone, unmeasured		..	..
Shale		15	0
Coal and dark shale	*Middle Kittanning*	..	6
Coal	*Middle Kittanning*	2	1
Shale	*Middle Kittanning*	..	1
Coal	*Middle Kittanning*	1	11
Clay, light to dark, plastic		6	6
Ore, nodular		..	4
Shale		11	8
Coal, *Lower Kittanning*		1	6
Clay, light to dark		12	6

Sections have been secured showing at least 12 feet of shale overlying the Middle Kittanning coal in the vicinity of Dover, Dover Township, 10 feet of shale in Section 8, Fairfield Township, and 17 feet of shale with overlying sandstone in Section 24, Lawrence Township. Lower Freeport shale is not utilized to any great extent for brick or tile in Tuscarawas County.

Carroll County. In Carroll County the Lower Freeport member outcrops above drainage in parts of Orange, Monroe, Rose, and Brown townships. The member offers possibilities in this county as a source of material for ceramic products as the exposures are generally favorably located with respect to drainage levels and as the material is a sandy shale which yields a satisfactory product. Lower Freeport shale with small quantities of clay are utilized for the manufacture of sewer pipe by the Robinson Clay Products Company at the Malvern Plant, located in Section 20, Brown Township. The shale is supplied from open cuts and the clay from underground workings. A description of the exposures in the pit is as follows:

		Ft.	In.
Shale, gray, sandy	*Lower Freeport*	33	0
Shale, dark, with ore nodules	*Lower Freeport*	8	8
Coal horizon, *Middle Kittanning*		..	..

A sample of the Lower Freeport shale was taken from this pit by A. E. MacGee of the National Bureau of Standards.

Sample No. 207

Tests of Lower Freeport shale from the pit of the Robinson Clay Products Company, Malvern, Carroll County. (Tests by the Bureau of Standards)[1]

Chemical analysis

Loss on ignition	6.6
Silica, SiO_2	57.5
Alumina, Al_2O_3	19.3
Ferric oxide, Fe_2O_3	8.3
Lime, CaO	0.4
Magnesia, MgO	2.0
Titanic oxide, TiO_2	1.0
Sodium oxide, Na_2O	0.8
Potassium oxide, K_2O	3.0
Sulphur, S	0.1
Total carbon, C	0.9

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .15 \\ Na_2O & .04 \\ CaO & .02 \\ MgO & .10 \\ FeO & .39 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 2.98 \\ TiO_2 & 0.05 \end{array}\right.$$

RO .70

Physical tests

Tempering water:	About 22 per cent
Drying linear shrinkage:	About 3 or 4 per cent
Drying volume shrinkage:	About 10 per cent

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	1.3	3.8	17.3	Buff
Cone 06	2.6	7.5	14.3	Reddish buff
Cone 04	5.3	15.2	9.4	Reddish brown
Cone 03	8.3	23.0	4.3	Brick red
Cone 3	9.8	26.6	2.4	Red
Cone 4	9.8	26.5	1.6	Maroon

Overburning temperature: Cone 5 (1,180°C. or 2,156°F.).

Best apparent burning range: Cone 06 to cone 3 (1,005°C. to 1,145°C. or 1,841°F. to 2,093°F.).

Total linear shrinkage at cone 3: About 13 per cent.

Deformation temperature: Cone 10 to cone 11 (1,260°C. to 1,285°C. or 2,300°F. to 2,345°F.).

At the plant of the Metropolitan Paving Brick Company at Minerva, Lower Freeport shale 20 feet in thickness overlies the Middle Kittanning coal.

Stark County. The Lower Freeport shale outcrops in the eastern and southeastern portions of Stark County including parts of Pike, Sandy, Osnaburg, Paris, Washington, and Lexington townships. The shale in this area has good ceramic qualities and fair continuity and serves as one source of material for operations of moderate size. Lower Freeport shale supplies the plant of the National Fireproofing Company, in Section 28, Sandy Township, a short distance west of the village of Waynesburg.

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

The product consists of building block and various types of fire-proofing. A description of the exposures in the pit is given below:

		Ft.	In.
Glacial drift		8	0
Shale, grayish blue, soft at bottom, becoming harder and more sandy and micaceous upward	*Lower Freeport*	56	0
Bottom of pit		..	..
Shale and covered		5	8
Coal, *Middle Kittanning*		3	6
Clay, bluish, siliceous, not entire thickness		5	0

The glacial drift material at the top of the cut is stripped by shovel. The shale used in the plant, having a thickness of 56 feet in the above section, was sampled for testing on September 12, 1929. The results of the various tests are as follows:

Sample No. 35

Tests of Lower Freeport shale from pit of the National Fireproofing Company, Waynesburg, Stark County.

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.44
Water, combined, H_2O+	5.83
Silica, SiO_2	57.92
Alumina, Al_2O_3	17.91
Titanic oxide, TiO_2	1.15
Phosphorus pentoxide, P_2O_5	0.28
Ferric oxide, Fe_2O_3	3.86
Ferrous oxide, FeO	3.12
Lime, CaO	0.68
Magnesia, MgO	1.96
Sodium oxide, Na_2O	0.44
Potassium oxide, K_2O	3.02
Manganese oxide, MnO	0.07
Sulphur trioxide, SO_3	0.17
Ferrous sulphide, FeS_2	0.27
Carbon dioxide, CO_2	0.70
Carbon, organic, C	1.35

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .169 \\ Na_2O & .024 \\ CaO & .038 \\ MgO & .109 \\ FeO & .377 \\ MnO & .004 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.234 \\ TiO_2 & 0.064 \\ P_2O_5 & 0.015 \end{array}\right.$$

$$\begin{array}{ll} RO & .721 \end{array}$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has good plasticity. A good column is extruded from the die.

Time of slaking: 11.22 minutes.

Water of plasticity: 16.95 per cent.

Dry shrinkage:

Volume: 7.54 per cent.

Linear: 2.45 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 293 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	28.37	11.27	3.6	14.73	1.93	2.68
04	21.58	16.41	5.2	5.53	2.06	2.33
02	16.53	20.45	6.4	6.04	2.17	2.50
1	12.70	23.88	7.4	5.64	2.26	2.58
3	10.08	26.71	8.2	4.34	2.34	2.60
5	6.32	27.33	8.4	2.67	2.37	2.53
7	5.39	24.36	7.5	2.21	2.26	2.38

Fired modulus of rupture:
Cone 05, 2,592 pounds per square inch.
Cone 4, 3,482 pounds per square inch.

Fired specific impact strength:
Cone 05, 1.41 centimeter kilograms per square centimeter.
Cone 4, 1.30 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 4, 11,449 pounds per square inch.

Best firing range: Cone 06 to cone 5.

Overfiring temperature: Cone 7.

Pyrometric cone equivalent: Cone 11.

Scumming: Scum occurs on all trials fired to cone 1 and lower but scum is not apparent on trials fired above cone 1. Four pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The salt glaze produced at 2,100°F. has a reddish brown color with a little yellowish green mottling. When $BaCO_3$ is added the glaze has a chocolate brown color.

Utilization: This shale was being used for the production of hollow tile. This material can be used also for drain tile, face brick, and common brick. The fired material develops a good red color at cone 02.

At the plant of the Mapleton Clay Products Company, formerly known as Keim Brick and Tile Company, located near Mapleton Station in Section 23, Osnaburg Township, Lower Freeport shale is utilized for red face brick. Other materials worked at this plant include the Lower and Middle Kittanning clays and the Strasburg shale. A section of the exposures in the pit is given below:

		Ft.	In.
Glacial drift		6	0
Shale, bluish gray, soft at bottom, becoming harder and more sandy and micaceous upward	*Lower Freeport*	23	0
Shale, bluish gray, soft, with ore nodules	*Lower Freeport*	3	6
Coal, bony	*Middle Kittanning*	..	2
Coal, good	*Middle Kittanning*	2	4
Clay, bluish gray, siliceous		8	8
Shale, gray, *Strasburg*		21	0
Coal, *Lower Kittanning*		2	8
Clay, gray, plastic	*Lower Kittanning*	5	0
Clay, gray, siliceous	*Lower Kittanning*	10	8

The $3\frac{1}{2}$-foot bed of shale immediately overlying the Middle Kittanning coal is discarded as the content of iron is too high to yield the best results. The material overlying this shale is less ferruginous and produces a satisfactory product. A sample of the 23-foot bed of shale described in the section was cut on September 10, 1929, and submitted for testing. The results are tabulated below:

Sample No. 33

Tests of Lower Freeport shale from pit of Mapleton Clay Products Company, Mapleton Station, Stark County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.21
Water, combined, H_2O+...	5.22
Silica, SiO_2	60.74
Alumina, Al_2O_3	17.78
Titanic oxide, TiO_2	1.29
Phosphorus pentoxide, P_2O_5	0.24
Ferric oxide, Fe_2O_3	5.43
Ferrous oxide, FeO........	1.59
Lime, CaO	0.55
Magnesia, MgO	1.79
Sodium oxide, Na_2O	0.41
Potassium oxide, K_2O	2.97
Manganese oxide, MnO....	0.07
Sulphur, S	0.10
Carbon dioxide, CO_2	0.15
Carbon, organic, C	0.62

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .167 \\ Na_2O & .023 \\ CaO & .031 \\ MgO & .101 \\ FeO & .364 \\ MnO & .004 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.416 \\ TiO_2 & 0.073 \\ P_2O_5 & 0.013 \end{array}\right.$$

$$\begin{array}{ll} RO & .690 \end{array}$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has short plasticity. A badly featheredged column is extruded from the die.

Time of slaking: 5.71 minutes.

Water of plasticity: 20.38 per cent.

Dry shrinkage:

Volume: 7.65 per cent.

Linear: 2.49 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 250 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	26.82	7.83	2.5	14.04	1.92	2.59
04	23.54	12.23	3.9	11.87	2.00	2.59
02	18.76	15.02	4.8	9.10	2.08	2.51
1	14.96	19.22	6.0	6.89	2.18	2.56
3	12.15	24.81	7.7	5.26	2.30	2.63
5	6.86	25.81	7.9	2.87	2.36	2.53
7	2.04	24.72	7.6	0.88	2.33	2.37

Fired modulus of rupture:
Cone 02, 1,876 pounds per square inch.
Cone 5, 3,620 pounds per square inch.
Fired specific impact strength:
Cone 03, 1.49 centimeter kilograms per square centimeter.
Cone 4, 1.43 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 5, 16,665 pounds per square inch.
Best firing range: Cone 06 to cone 5.
Overfiring temperature: Cone 7.
Pyrometric cone equivalent: Cone 12.

Scumming: Scum occurs on all trials fired to cone 5 and lower but scum is not apparent on trials fired above cone 5. Three pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The salt glaze produced at 2,050°F. is brown with a slight yellowish green shade. When $BaCO_3$ is added the color of the glaze produced at 2,100°F. is a chocolate brown.

Utilization: This shale was being used for the production of face brick. It can be used also for the production of common brick. The fired material develops a good red color at cone 1.

Lower Freeport shale is likewise utilized to some extent at the East Canton plant of the National Fireproofing Company located in Section 17, Osnaburg Township, where building block and fireproofing are the chief products. A section of the exposures at the plant is as follows:[1]

		Ft.	In.
Shale, gray	*Lower Freeport*	20	0
Shale, gray, with concretions	*Lower Freeport*	11	0
Coal, *Middle Kittanning*		3	9
Clay, dark, plastic, *Middle Kittanning*		8	0
Coal, *Strasburg*		..	9
Clay, dark, plastic		2	0
Clay, light, siliceous		6	0

The 11-foot bed of Lower Freeport shale is discarded as the concretions are detrimental. Lower Freeport shale is utilized to some extent at Alliance in Lexington Township, but as the plants are located in Mahoning County the discussion of the deposits is given under that heading.

Mahoning County. The Lower Freeport shale lies near the surface along the southern edge of Mahoning County, but the glacial drift deposits have so obscured the horizon that little is known concerning the nature of the material. Shale from this horizon has been utilized in Smith Township only.

At plants Nos. 1 and 2 of the Alliance Clay Products Company of Alliance, the Lower Freeport shale furnishes the chief source of supply although both Middle Kittanning clay and Strasburg shale are utilized to some extent. The plants are located in Section 31, Smith Township, Mahoning County, but the pit from which the material is taken is situated

[1] Geol. Survey Ohio, 4th Ser., Bull. 26, p. 407, 1923.

across the county line in Section 36, Lexington Township, Stark County. The character and thickness of the exposures in the pit are described below:

		Ft.	In.
Shale, gray, sandy	*Lower Freeport*	6	0
Shale, bluish gray, sandy	*Lower Freeport*	22	3
Coal, *Middle Kittanning*		2	6
Clay, bluish gray, siliceous, *Middle Kittanning*		14	0
Shale, bluish gray, sandy, a few ore nodules.	*Strasburg*	7	3
Sandstone	*Strasburg*	1	0
Shale, bluish gray, some ore nodules	*Strasburg*	6	6

Lower Freeport shale is also the basis for the operation of plant No. 2 of the Alliance Brick Company, likewise located in Section 31, Smith Township. At plant No. 1 situated in Section 29, Smith Township, about midway between Alliance and Sebring, the Lower Freeport shale was formerly used with the Middle Kittanning clay for face brick.

Sample No. 24

Tests of Lower Freeport shale from pit of the Alliance Clay Products Company, Alliance, Mahoning County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	0.50
Water, combined, H_2O+	5.10
Silica, SiO_2	62.81
Alumina, Al_2O_3	16.71
Titanic oxide, TiO_2	1.01
Phosphorus pentoxide, P_2O_5	0.17
Ferric oxide, Fe_2O_3	3.10
Ferrous oxide, FeO	3.40
Lime, CaO	0.71
Magnesia, MgO	1.88
Sodium oxide, Na_2O	0.33
Potassium oxide, K_2O	2.64
Manganese oxide, MnO	0.04
Sulphur, S	0.10
Carbon dioxide, CO_2	1.02
Carbon, organic, C	0.77

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .158 \\ Na_2O & .020 \\ CaO & .042 \\ MgO & .113 \\ FeO & .370 \\ MnO & .002 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.759 \\ TiO_2 & 0.060 \\ P_2O_5 & 0.010 \end{array}\right.$$

RO .705

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This shale has short plasticity. A featheredged column is extruded from the die.

Time of slaking: 5.76 minutes.

Water of plasticity: 19.33 per cent.

Dry shrinkage:

Volume: 10.91 per cent.

Linear: 3.51 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 160 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	27.40	7.67	2.5	14.53	1.88	2.60
04	24.30	10.84	3.5	12.32	1.98	2.60
02	22.10	14.95	4.8	10.75	2.07	3.14
1	19.74	17.91	5.7	9.28	2.13	3.16
3	17.23	19.72	6.2	7.90	2.17	2.63
5	11.85	20.90	6.5	5.31	2.24	2.53
7	8.24	21.91	6.8	3.69	2.23	2.43

Fired modulus of rupture:
Cone 05, 1,418 pounds per square inch.
Cone 5, 2,825 pounds per square inch.

Fired specific impact strength:
Cone 05, 1.46 centimeter kilograms per square centimeter.
Cone 4, 1.53 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 5, 12,530 pounds per square inch.

Best firing range: Cone 06 to cone 7.

Overfiring temperature: Cone 9.

Pyrometric cone equivalent: Cone 13.

Scumming: Scum occurs on all trials fired to cone 3 and lower but scum is not apparent on trials fired above cone 3. Four pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: A good salt glaze is produced at 2,050°F. The color is a brownish green mottle grading to a reddish brown. When $BaCO_3$ is added the color of the glaze produced at 2,100°F. is a chocolate brown.

Utilization: This shale was being utilized for the production of face brick. It can be used also for common brick. On firing a good red color is produced at cone 02.

Columbiana County. The Lower Freeport horizon is of wide extent in Columbiana County as it outcrops in Knox, Butler, Perry, Salem, Center, Elk Run, Middleton, Unity, St. Clair, Liverpool, Yellow Creek, Wayne, and Washington townships. Over a portion of the area, however, massive sandstone is developed which occupies a part or the entire horizon and in some localities replaces the Middle Kittanning coal. Such phases of the member are prominently developed along Middle Fork in Salem, Center, Elk Run, and St. Clair townships; along Middle Fork in Madison Township; along North Fork in Middleton Township; and along the Ohio River in Liverpool and Yellow Creek townships. Where this sandstone either thins or disappears its place is taken by sandy shales. Such shale deposits are prominently developed in western Yellow Creek and Unity townships and at places in eastern Liverpool Township. At a few places in the eastern part of the county a thin blossom of Upper Kittanning coal is present, lying about 18 feet on an average above the Middle Kittanning coal.

The following record is from Section 35, Unity Township:[1]

[1] Geol. Survey Ohio, 4th Ser., Bull. 28, p. 162, 1924.

		Ft.	In.
Coal, *Lower Freeport*		..	11
Clay, gray, plastic		2	6
Clay, flinty, calcareous		3	6
Clay, with ore nodules		1	0
Sandstone, with ore nodules		3	6
Clay, gray, siliceous, with ore nodules		5	8
Sandstone	*Lower Freeport*	..	6
Shale, gray, argillaceous	*Lower Freeport*	12	8
Shale, very siliceous	*Lower Freeport*	33	2
Covered	*Lower Freeport*	16	6
Shale, black		2	0
Coal, *Middle Kittanning*		..	6

Lower Freeport shale is not utilized for ceramic products in Columbiana County.

Jefferson County. In Jefferson County the Lower Freeport horizon is above drainage along the Ohio River Valley as far south as Toronto; along Yellow Creek and its tributaries, Brush Creek and North Fork, in Saline Township; and along Brush Creek in southeastern Brush Creek Township. In this area the member is represented by sandstone and very sandy shale and therefore it has little value as a source for ceramic materials.

Upper Freeport Shale

Sandstone and shale of variable thickness, but averaging about 33 feet in Ohio, comprise the interval between the Lower Freeport coal and the Bolivar clay. The name Upper Freeport has been used in geologic literature for the prominent sandstone developed on this horizon in some localities, but for purposes of convenience in description this term will be extended to include the corresponding shale facies. Sandstone on the Upper Freeport horizon is in general local in its development in Ohio. Where the sandstone disappears from the section, it gives way to gray sandy shale of variable texture. Outcrops of the Upper Freeport horizon extend entirely across the State from Lawrence and Gallia counties on the south to Columbiana and Jefferson counties on the east. Since the Upper Freeport shale adds little to the ceramic wealth of the State, having been utilized at only one locality, its character and distribution are considered in a very general way in the following pages.

Lawrence County. The belt of outcrops of the Upper Freeport horizon extends north and south through the central part of Lawrence County, including parts of Fayette, Perry, Upper, Elizabeth, Lawrence, Aid, Decatur, Symmes, and Washington townships. Shale is found over local areas in this county, but the member is predominantly sandstone. The thickness varies from 30 to 50 feet but averages about 40 feet. Near Waterloo, Symmes Township, the Upper Freeport is almost entirely a siliceous shale with a thickness of about 30 feet. Much the same condition exists near Center Station in Decatur Township. The following section secured near Kitts Hill in Lawrence County shows the prevailing situation:[1]

		Ft.	In.
Clay, part flint, *Upper Freeport* horizon		2	0
Shale and shaly sandstone, *Upper Freeport*		44	0
Coal stain, *Lower Freeport*		..	6
Clay and covered	*Lower Freeport*	5	0
Sandstone, shaly	*Lower Freeport*	4	0
Sandstone	*Lower Freeport*	29	0
Covered	*Lower Freeport*	5	0
Coal blossom, *Middle Kittanning*		3	0

The Upper Freeport coal is of most importance in the Symmes Creek Basin in Symmes Township.

Gallia, Jackson, and Vinton Counties. The Upper Freeport member in Gallia County merits little consideration for on the outcrops through Walnut, Greenfield, Perry, Raccoon, and Huntington townships it is composed almost entirely of massive sandstone. In eastern Jackson County the outcrops are near the summits of the high hills and ridges in Madison, Bloomfield, and Milton townships. Sandstone is locally developed in this area but where it is wanting its place is taken by sandy shales. From Gallia and eastern Jackson counties the outcrops extend north through eastern Vinton County, being represented in Wilkesville, Vinton, Madison, Knox, and Brown townships. Here also local deposits of sandstone occur, but the horizon is one composed chiefly of sandy shale. The average thickness is almost 28 feet. In Section 30, Wilkesville Township, the Lower Freeport clay is overlain by 14 feet of sandstone above which is 20 feet of siliceous shale. In Section 31, Vinton Township, the member is represented by 20 feet of gray sandy shale. The following record secured by Wilber Stout from Section 16, Madison Township, is typical for the shale facies of the Upper Freeport:

		Ft.	In.
Clay, red, shaly		3	0
Shale and covered		2	0
Clay, light		2	0
Sandstone, shaly	*Upper Freeport*	3	0
Shale, gray, and covered	*Upper Freeport*	22	0
Clay, shaly, and covered, *Lower Freeport*		3	0
Limestone, nodules in clay, *Lower Freeport*		1	0

Hocking, Athens, and Perry Counties. The Upper Freeport shale horizon is of slight importance in Hocking County as the exposures are small in area and are confined to the higher hills and ridges in eastern

[1] Geol. Survey Ohio, 4th Ser., Bull. 20, p. 398, 1916.

Starr and Ward townships. In Athens County the member is above drainage over small areas in Lee and Waterloo townships and over a larger area in York Township. Along the Hocking Valley in Dover Township and along Sunday Creek in Dover and Trimble townships the Upper Freeport coal horizon lies close to drainage level and therefore only a small part of the underlying beds are exposed. In parts of Waterloo Township the Bolivar clay is found separated from the Upper Freeport horizon by a few feet of shale. Wilber Stout secured the following records from Section 26, Waterloo Township:

	Ft.	In.
Clay, light to dark, plastic, *Upper Freeport*	4	0
Shale, gray	11	0
Coal blossom	1	0
Clay with nodules of limestone, *Bolivar*	15	0
Shale, gray, *Upper Freeport*	10	0
Coal blossom, *Lower Freeport*	1	0

Near the pit of the Nelsonville Brick Company at Nelsonville the Lower Freeport coal is overlain by about 25 feet of gray sandy shale above which is massive sandstone.

The belt of outcrops of the Upper Freeport shale horizon passes northward from western Athens and eastern Hocking counties through eastern Perry County where the characteristics of the member undergo little change. At places massive sandstone marks the horizon and at other localities the sandstone disappears and the interval becomes so short that the Bolivar clay lies close above the Lower Freeport coal.

Muskingum, Guernsey, Coshocton, and Holmes Counties. The Upper Freeport shale horizon extends across the central part of Muskingum County, but it is represented by local deposits of sandstone in every township where outcrops occur which include all or parts of Clay, Newton, Brush Creek, Harrison, Blue Rock, Wayne, Salt Creek, Washington, Perry, Salem, Madison, Adams, Monroe, and Highland townships. In places thin beds of sandy shale occur interstratified with the sandstone, but at other localities the sandstone gives way entirely to siliceous shale. In Guernsey County, where the exposures are found along Wills Creek Valley and its tributaries from Byesville north through parts of Adams, Cambridge, Center, Knox, Liberty, Jefferson, Wheeling, Monroe, and Washington townships, sandstone is prominently developed on the Upper Freeport shale horizon, although in places small bodies of siliceous shale occur. Similar conditions are believed to exist in eastern Coshocton County where the Upper Freeport underlies the higher elevations. Scattered outcrops of the Upper Freeport member are also found in southeastern Holmes County where the material is sandstone and sandy shale.

Tuscarawas, Carroll, and Stark Counties. The Upper Freeport shale horizon outcrops in every township in Tuscarawas County with the exception of Lawrence, Franklin, Wayne, and Sugar Creek, all of which are located in the northwest corner. West of the Tuscarawas River the member occurs chiefly as isolated areas outcropping near the crests of the hills and ridges, but east of the river and south of Sandy Creek the member occurs at lower levels and the field is less broken by drainage lines. Along Stillwater and Little Stillwater creeks the exposures extend to the southeast and east into Harrison County, but the extent of the outcrops is small. Both shale and sandstone are represented on the Upper Freeport horizon in these areas.

The Upper Freeport shale horizon also extends into Carroll County where exposures occur along the larger drainage courses in the northwest half of the county. The Lower Freeport coal is poorly developed in Carroll County and the underlying beds consist of both shale and sandstone.

In Stark County the outcrops of the Upper Freeport are confined to the southeastern portion including parts of Sandy, Osnaburg, Paris, and Washington townships. Shale from this horizon was formerly used for face brick at the Robertsville plant of the Canton Brick and Fire Proofing Company at Robertsville in Section 19, Paris Township. A section of the exposures measured by Wilber Stout is as follows:

		Ft.	In.
Shale		12	0
Coal, *Upper Freeport*		2	0
Clay, dark, limestone concretions in lower part		14	0
Limestone, nodular, *Upper Freeport*		1	0
Shale, soft, light	*Upper Freeport*	3	0
Shale, gray, sandy	*Upper Freeport*	25	0

Columbiana and Jefferson Counties. In Columbiana County the Upper Freeport horizon is above drainage over a wide area as exposures occur in every township. Shale of somewhat varying composition and color is the chief material comprising the member although lenses of shaly sandstone embedded in the shale are widespread in their occurrence. The average thickness of the member is about 38 feet. The following measurements from Section 11, Yellow Creek Township, show this shale in its best state of development:[1]

		Ft.	In.
Coal, *Upper Freeport,* reported thickness		2	4
Clay, light, plastic		5	0
Shale, gray, siliceous, *Upper Freeport*		52	0
Coal, shaly	*Lower Freeport*	..	1
Coal, good	*Lower Freeport*	1	2

No attempt has been made to utilize the Upper Freeport shale for ceramic purposes in Columbiana County. In Jefferson County the outcrops

[1] Geol. Survey Ohio, 4th Ser., Bull. 28, p. 210, 1924.

of the member are limited to the valleys of Yellow Creek and its tributaries in Ross, Knox, Saline, and Brush Creek townships and to the Ohio River Valley in Saline, Knox, and Island Creek townships. Throughout this area the Upper Freeport consists chiefly of sandstone, which in many places is massive.

Conemaugh Series

The rock strata overlying the Upper Freeport coal and extending to the base of the Pittsburgh coal comprise the third subdivision of the Pennsylvanian system known as the Conemaugh series. In contrast to the Pottsville and Allegheny the Conemaugh is relatively unimportant as a source of materials of economic value. The coal beds, twelve in number, are patchy in distribution and are generally too thin for profitable mining, and the underlying clays are generally calcareous and ferruginous as are also a large percentage of the shale deposits. Limestone, which is relatively important in the Conemaugh series, supplies some material for local demands. The outcrops of the Conemaugh in Ohio comprise a belt varying from 10 to 40 miles in width and extending across southeastern Ohio from the Ohio River in Gallia and Lawrence counties on the south to the Ohio-Pennsylvania-West Virginia line in Columbiana, Jefferson, and Belmont counties on the east. In addition to those counties already mentioned, this belt of outcrops includes parts of Jackson, Meigs, Vinton, Athens, Hocking, Perry, Morgan, Muskingum, Noble, Guernsey, Coshocton, Tuscarawas, Harrison, Stark, and Carroll counties.

The thickness of the Conemaugh series in Ohio varies from 350 feet in the southern part in Lawrence County to 518 feet at the eastern edge in Jefferson County. The average for the outcrops in this State as a whole, however, is about 400 feet. A generalized section of the Conemaugh series of Ohio showing the stratigraphic succession, the names of the most important members, and their average thickness on the outcrop is given below:

Generalized Section of the Conemaugh Series of Ohio[1]

Series	Member	General description	Thickness Ft.	In.
Conemaugh		Shale, soft	..	6
	Pittsburgh	Limestone, irregular	5	0
	Upper Little Pittsburgh	Shale, soft	13	5
	Upper Little Pittsburgh	Coal, very local	..	1
	Bellaire	Sandstone and shale	17	0
	Lower Little Pittsburgh	Coal, seldom present	..	1
	Summerfield	Shale, variable	8	0
	Summerfield	Limestone	12	0
	Connellsville	Shale and sandstone	48	10
	Clarksburg	Coal, local	..	2
	Clarksburg	Limestone and marly shale	4	0
	Morgantown	Sandstone, local, and shale	30	0
	Elk Lick	Coal, usually wanting	..	1
	Elk Lick	Limestone and marly shale	5	0
	Birmingham	Shale, variable	15	0
	Skelley	Limestone, local, marine	..	4
	Duquesne	Coal, seldom evident	..	1
	Ames	Shale, sandy	37	0
	Ames	Limestone, marine	1	6
	Harlem	Shale, sandy	15	0
	Harlem	Coal, persistent Clay, calcareous	1 3	0 0
	Round Knob	Shale, soft, red	12	0
	Saltzburg	Sandstone, local, and shale	10	0
	Barton	Coal, local	1	0
	Cow Run	Shale and sandstone	25	4
	Portersville	Limestone and fossiliferous shale, marine	2	0
	Anderson	Coal, persistent	1	8
	Wilgus	Shale, variable	24	0
	Cambridge	Limestone, marine	4	0
	Wilgus	Coal, unsteady	2	0
	Buffalo	Shale and sandstone	26	8
	Brush Creek	Limestone and fossiliferous shale, marine	20	0
	Brush Creek	Coal, local, thin	..	4
	Mason	Shales, variable	10	6
	Mason	Coal, local	..	6
	Upper Mahoning	Shale and sandstone	10	0
	Mahoning	Coal	1	0
	Thornton	Clay, irregular	5	0
	Mahoning	Limestone, local	2	0
	Lower Mahoning	Shale and sandstone	25	0

When the Pennsylvanian rocks first began to attract the attention of geologists the conspicuous beds, such as coal, limestone, and sandstone, were given names which were usually determined by the localities where they were prominently developed or where they were of particular value.

[1] Geol. Survey Ohio, 4th Ser., Bull. 34, opposite p. 6, 1929.

As the rock classification developed, such names have often been retained in the rank of members. In general few names have been applied to shale beds although in an economic sense they are of some importance. For convenience in description in this report the shale beds are in general given the name of the first underlying coal except where the shale is found on the same stratigraphic horizon as a prominent sandstone member which has been named. In the latter case the term applied to the sandstone is used for the shale occurring on the same horizon.

Conemaugh Shales Below the Brush Creek Fossiliferous Beds

The Conemaugh series of Ohio below the Brush Creek fossiliferous beds consists of sandstone, shale, clay, limestone, and coal, but the economic importance of the series is small. The clays are generally calcareous and ferruginous in character; the limestones are thin, nodular and discontinuous; and the coal except in a few localities is too thin for profitable mining. In descending order the members of the Conemaugh series below the Brush Creek beds are as follows:

Brush Creek coal
Mason shale
Mason coal
Upper Mahoning sandstone and shale
Mahoning coal
Thornton clay
Mahoning limestone
Lower Mahoning sandstone and shale.

In Ohio the combined thickness of these beds on the outcrop ranges from about 30 to 125 feet but the average is about 54 feet. The outcrops extend from the Ohio River in Lawrence and Gallia counties northeast to the Ohio-Pennsylvania-West Virginia line in Columbiana, Jefferson, and Belmont counties. The base of this series is marked by the top of the Upper Freeport coal or, where the coal is wanting, by its underlying clay. From the Upper Freeport horizon the series extends up to the base of the Brush Creek marine beds consisting of fossiliferous limestones and shales. Within the series below the Brush Creek are three shale horizons of possible ceramic value, namely the Mason and Upper and Lower Mahoning, which are separated by coal and clay horizons of more stratigraphic than economic interest. The Mahoning clay is widely distributed but patchy in occurrence whereas the overlying coal is either generally wanting or is represented by only a few inches of black shale or shaly coal, except in Columbiana and Jefferson counties where the bed is of minable thickness and of good quality. The Mason coal horizon is likewise of wide occurrence but it is usually represented by only a few inches of black shale or shaly coal. In some localities it carries a thin impure clay below it.

The Lower and Upper Mahoning shale horizons carry much sandstone in Ohio; in fact these names were first applied to massive sandstones developed on their horizons. The Lower Mahoning sandstone is present over large areas, being prominently developed along the Symmes Creek Valley in northern Lawrence County, in Guernsey County, and in parts of Carroll, Jefferson, and Columbiana counties. In some localities it is conglomeratic at its base. The Upper Mahoning sandstone in general tends to be shaly, lens-like in character, and patchy in its distribution although in places it becomes massive, coalescing with the Lower Mahoning sandstone below and elsewhere with the Buffalo sandstone above. In parts of the outcrop areas soft red calcareous shales are present on the Upper Mahoning horizon. Due to the changeable character of Conemaugh beds below the Brush Creek and to the small economic importance of the shales, the Mason and Upper and Lower Mahoning are considered together in the following description.

Character and Areal Extent

The lower Conemaugh beds outcrop over a north and south belt through Lawrence County, including parts of Fayette, Perry, Lawrence, Upper, Elizabeth, Aid, Symmes, Decatur, and Washington townships. In this locality the Lower and Upper Mahoning horizons consist chiefly of sandstone although small areas of very sandy shales occur. The Mason horizon is also marked by similar material. In western Gallia County, where exposures of these beds are present through Huntington, Raccoon, Perry, Walnut, and Greenfield townships, similar conditions are found but sandstone is not quite so prominently developed. In Section 28, Morgan Township, the Upper Mahoning and Mason horizons are represented by some 50 feet of sandy shale. Similar conditions exist on the Lower Mahoning horizon in Section 32, Raccoon Township. In Greenfield, Walnut, and Perry townships, the Mason and Mahoning coal horizons are not definitely marked and the strata below the Brush Creek horizon consist of red and gray shales of changeable facies. The following section measured by Wilber Stout in Section 31, Greenfield Township, shows this variable character:

	Ft.	In.
Limestone, *Brush Creek*	2	0
Shale, soft	5	0
Sandstone, shaly, and covered	26	0
Sandstone, shaly, and sandy shale	24	0
Shale and covered	20	0
Shale, soft, red, with nodules of limestone	15	0
Sandstone, ferruginous, shaly	2	0
Shale, gray	6	0
Sandstone	2	0
Shale, gray	9	0
Shale and covered	9	0

	Ft.	In.
Shale, red	2	0
Shale, soft, mottled red	3	0
Shale, sandy	6	0
Coal horizon, *Upper Freeport*	..	..

The lower Conemaugh beds are limited in area in Jackson County as they are found only near the crests of the highest hills and ridges along its eastern margin. They occupy much the same topographic position in eastern Vinton County although the areal extent of the outcrops is greater. The Lower Mahoning horizon is marked by sandstone of variable thickness throughout northeast Brown, east-central Madison, and east and central Vinton townships. It is rather regularly developed throughout Knox Township as is also the Upper Mahoning sandstone. When these sandstones are wanting their place is taken by sandy shale. Shale of somewhat variable character is also found in many localities above the Mason coal. The average thickness of the Conemaugh series below the Brush Creek in Vinton County is about 70 feet. The following record by Wilber Stout from Sections 11 and 12, Vinton Township, illustrates the character and succession of the shale deposits.

		Ft.	In.
Limestone, blue, fossiliferous, *Brush Creek*		..	5
Shale, gray, and shaly sandstone	*Mason*	14	0
Shale, gray	*Mason*	18	0
Coal and black shale, *Mason*		1	0
Shale, gray and red		18	0
Shale, soft, red		2	0
Shale and covered		14	0
Shale, part sandy		40	0
Shale and shaly sandstone		12	0
Coal horizon, *Upper Freeport*		..	..

In Meigs County the outcrops of the lower part of the Conemaugh series are confined chiefly to Columbia and Salem townships along its western edge. Here great variability in composition characterizes the beds. Sandstone is present on both the Lower and Upper Mahoning horizons but it is by no means continuous. In Section 34, Columbia Township, bodies of shale of good thickness occur above both the Mahoning and Mason coals. Similar deposits are found above the Mason coal in Section 28, Salem Township. In Athens County rocks of Conemaugh age below the Brush Creek beds are above drainage in Waterloo, Lee, York, Dover, and Trimble townships. Throughout this area massive sandstone is generally present on the Lower Mahoning shale horizon. In the vicinity of Nelsonville this sandstone has a thickness of about 50 feet; it forms bold cliffs of variable height a little above road level along portions of the lower Sunday Creek Valley. Local deposits of sandstone are also present on the Upper Freeport and Mason shale horizons but the predominating type of rock is a sandy shale. Shale immediately overlying the Mason coal horizon was formerly used at the brick plant of the Hisylvania Coal Company, located at Glouster, but the practice has been abandoned. In Starr and Ward townships, Hocking County, the basal rocks of the Conemaugh series cap the high hills and ridges but the areal extent of these beds is small.

Perry County, which lies just north of Athens and eastern Hocking counties, contains a large area of lower Conemaugh beds in its eastern part. The chief districts where these exposures occur are Harrison, Clayton, Pike, Bearfield, Pleasant, Coal, Salt Lick, and Monroe townships. Throughout this area sandstone is prominently developed below the Brush Creek beds. Much the same conditions occur in Morgan County where exposures are limited to western York Township and to the Muskingum Valley in Bloom Township. In Muskingum County the Conemaugh series below the Brush Creek outcrops in every township east of the Muskingum River with the exception of Meigs, Rich Hill, and Union, while west of the river exposures are present in Harrison, Brush Creek, and eastern Newton townships. In this county the Lower Mahoning horizon is chiefly a siliceous shale although bodies of shaly sandstone or massive sandstone are locally present. The massive sandstone phase is well developed in Monroe and northern Highland townships. The Upper Mahoning horizon is represented by deposits of shaly sandstone in a few localities but sandy shale is the chief type of rock found. Good bodies of shale are present on the Lower Mahoning horizon in parts of Harrison Township. In Section 30 the material is a sandy shale with a thickness of about 25 feet. Shale deposits are also present along the Muskingum Valley in Blue Rock Township as illustrated by the following record from the John Daw property:

		Ft.	In.
Clay with limestone nodules, *Cambridge*		3	0
Shale		25	0
Covered		9	0
Shale, siliceous	*Upper Mahoning*	10	0
Shale, gray	*Upper Mahoning*	4	0
Coal, *Mahoning*		..	2
Clay, *Thornton*		3	0
Covered	*Lower Mahoning*	10	0
Sandstone and covered	*Lower Mahoning*	12	0
Shale and covered	*Lower Mahoning*	7	0
Coal horizon, *Upper Freeport*		..	..

The Brush Creek beds, which are rather persistent throughout the county, occur about 25 feet below the Cambridge limestone, but are not shown in this record. In Section 23, Salem Township, the succession is as follows:

	Ft.	In.
Limestone, nodular, *Cambridge*	1	0
Shale, soft, and covered	10	0
Shale, gray	20	0
Sandstone, shaly	5	0
Shale, soft, red	3	0
Shale, gray	14	0
Shale, soft, upper part red	6	0
Shale, sandy, and shaly sandstone	27	0
Coal blossom, *Upper Freeport*	2	0

In Guernsey County sandstone is prominently developed in the lower part of the Conemaugh series, which outcrops over large areas in the northwestern two-thirds of the county. The beds are therefore of no importance as sources of material for ceramic products. A few isolated outliers of Conemaugh rocks are widely scattered over the eastern half of Coshocton County. In Tuscarawas County the main body of these deposits is found east of the Tuscarawas River. West of this river the outcrops of the Conemaugh rocks are confined to small patches forming the crests of the highest hills and ridges. The Conemaugh series below the Brush Creek horizon in this county is composed chiefly of shaly sandstone which gives way in places to sandy shale. At the plant of the Ross Clay Products Company in Section 25, Union Township, sandy shale forms the lower part of the Conemaugh series, as shown in the following section secured by Wilber Stout.

		Ft.	In.
Shale, sandy	*Upper Mahoning*	8	0
Shale, dark	*Upper Mahoning*	..	6
Coal, *Mahoning*		..	5
Clay		6	0
Clay, plastic, gray and mottled, with nodular limestone		5	0
Sandstone and sandy shale		25	0
Shale, gray		22	0
Shale, dark		6	0
Coal, *Upper Freeport*		3	0

Sandstone is prominently developed in the Conemaugh series below the Brush Creek beds in the outcrop areas in the western part of Harrison County. In Carroll County these beds are exposed over a large area in the northwestern half. Sandstone is present on the Lower and Upper Mahoning horizons in some localities but sandy shale with good thickness is present at other places. Much the same conditions prevail in Columbiana County, where the horizon of these members comes to the surface in parts of every township. The Mahoning coal is of minable thickness in parts of Unity, Middleton, Madison, Washington, and Yellow Creek townships. The following measurements of exposures in the railroad cut just east of Salineville show the shales in a good state of development.[1]

[1] Geol. Survey Ohio, 4th Ser., Bull. 28, p. 293, 1924.

		Ft.	In.
Shale, gray	Upper Mahoning	11	0
Shale, dark	Upper Mahoning	..	6
Coal, irregular, *Mahoning*		1	8
Shale, soft, dark, gray		3	6
Limestone, irregular, siliceous	Mahoning	2	10
Shale	Mahoning	..	2
Limestone, irregular, siliceous	Mahoning	..	10
Shale	Mahoning	..	5
Limestone, irregular, siliceous	Mahoning	..	7
Shale, siliceous, yellowish	Lower Mahoning	12	0
Shale and covered, reported thickness	Lower Mahoning	23	0
Coal, reported thickness, *Upper Freeport*		5	6

Shale overlying the Mahoning coal was formerly utilized by the Ohio Clay Products Company at Salineville. The practice has been discontinued. Bodies of shale occur above the Upper Freeport and Mahoning horizons at many places in Center and Elk Run townships. The following section describes exposures in the central part of Section 15, Elk Run Township.[1]

	Ft.	In.
Shale, dark with ore nodules, *Brush Creek*	6	0
Shale, soft, and covered	7	0
Shale, drab, part siliceous	20	0
Shale, soft, red and yellow	4	0
Shale, gray	3	0
Covered	10	0
Shale and covered	47	0
Shale, dark	1	2
Coal, *Mahoning*	1	4
Clay and covered	12	6
Shale and covered	11	0
Covered	3	0
Coal, *Upper Freeport*	3	0

In Jefferson County the Conemaugh series below the Brush Creek beds is above drainage along the valley of Yellow Creek from its mouth to western Springfield Township and along the Ohio River Valley from the northern boundary of the county to Stanton Park in Section 31, Island Creek Township. The series is characterized in this area by much sandstone with minor amounts of sandy shale. Over parts of the field both the Mahoning and Upper Freeport coals have been replaced by sandstone.

Brush Creek Shale

Shale is an important part of the Brush Creek member along its entire line of outcrop in Ohio which extends from Lawrence County on the south to Columbiana and Jefferson counties on the east. In addition to the shales which are generally fossiliferous, limestone either in regular

[1] Idem, p. 301-302.

beds or in the nodular form is nearly always present. At typical exposures in southern Ohio the Brush Creek member is composed of two thin beds of gray to dark fossiliferous limestone which are separated by a shale interval of 20 to 30 feet in thickness. This shale zone is generally siliceous, carbonaceous, and calcareous in composition. Brush Creek beds having these general characters are found on the outcrop through Lawrence, Gallia, Vinton, Meigs, Athens, Perry, and Morgan counties. At some localities in southern Ohio many thin layers of gray cherty limestone are so interbedded in the shales that the entire member consists of thin alternating zones of limestone and shale.

The following is a record of the exposures in Section 33, Morgan Township, Gallia County, and is representative of the succession in the Brush Creek beds of southern Ohio.[1]

		Ft.	In.
Limestone, *Cambridge*		2	3
Shale, mottled		9	3
Sandstone, nodular, ferruginous		1	0
Shale, gray, sandy		17	0
Limestone, fossiliferous	*Brush Creek*	1	10
Shale, soft, red	*Brush Creek*	3	0
Shale, gray, sandy	*Brush Creek*	11	0
Limestone, very fossiliferous	*Brush Creek*	1	6

In Athens County the Brush Creek shale was formerly used to some extent at the plants of the Trimble Brick Manufacturing Company and the Hisylvania Coal Company located at Trimble and Glouster, respectively. As the shale at these localities was too calcareous and carbonaçeous to produce a paving block of good quality, its use was discontinued.

In Muskingum and neighboring counties to the northeast the Brush Creek member generally consists of a single ledge of gray to dark limestone underlain with carbonaceous and calcareous shale. In Columbiana and Jefferson counties this member generally consists of a bed of somewhat sandy carbonaceous and fossiliferous shale through which nodular masses of black limestone are imbedded in an irregular manner. In some localities the limestone occurs as a distinct bed at the base of the shale. The thickness of the Brush Creek beds ranges from 1 to as much as 25 feet. At Summitville, in Franklin Township, Columbiana County, Brush Creek shale has been utilized to some extent by the Summitville Face Brick Company for the production of face brick. Most of the material, however, comes from the overlying Buffalo shale. At no place in Ohio is the Brush Creek shale used exclusively as a source of material for ceramic products.

[1] Geol. Survey Ohio, 4th Ser., Bull. 20, p. 653, 1916.

Buffalo Shale

The horizon of the Buffalo shale is the interval bounded by the Brush Creek beds below and the Wilgus coal and clay above or, in the absence of this coal horizon, by the Cambridge limestone which lies immediately above. The thickness of the Buffalo horizon in Ohio varies from 12 to 50 feet but the average is about 23 feet. The term Buffalo was first applied to deposits of massive sandstone on this horizon but for the sake of convenience in description the term is here extended to include the shale beds having the same stratigraphic position and age. The sandstone phase of the Buffalo in Ohio is very localized as massive deposits may occur at one locality and sandy shale at the next exposure. In general, however, shales are present on this horizon over much of the outcrops in Lawrence and Gallia counties; in local areas in eastern Vinton County; in Athens, western Morgan, and Perry counties; in central Guernsey, northwestern Harrison, Columbiana, and northern Jefferson counties. Buffalo sandstone is conspicuously developed along the Leading Creek Valley in Meigs County, in portions of eastern Vinton County, in Muskingum, western Guernsey, Tuscarawas, southwestern Harrison, Carroll, and central Jefferson counties. As Buffalo shale has supplied the raw material for the manufacture of brick and tile at a number of localities in Ohio the general features of the bed will be traced across the State.

Areal Distribution and Character

In Lawrence County the Buffalo horizon outcrops over a north-south belt including large areas in Fayette, Perry, Lawrence, Aid, and Symmes townships and smaller areas in adjacent districts bordering on the east and west. Near Burlington in Fayettte Township the Buffalo member is composed of shale with a thickness of about 15 feet. Much the same condition exists in Section 13, Union Township. In parts of Lawrence Township sandstone is prominently developed but shale again appears in the Symmes Creek Valley in Symmes Township. The following is a record of exposures one mile east of Waterloo:[1]

		Ft.	In.
Limestone, fossiliferous, *Cambridge*		2	9
Coal, reported thickness, *Wilgus*		2	4
Shale, soft, *Buffalo*		13	1
Rock, fossiliferous, cherty	*Brush Creek*	..	10
Limestone	*Brush Creek*	1	0

From Lawrence County the belt of exposures of the Buffalo horizon extends north through western Gallia County where outcrops are present in Greenfield, Walnut, Perry, Raccoon, Huntington, and Morgan townships. The material here is chiefly a sandy shale, with an average thickness of about 20 feet. In a few localities the shale is soft and clay-like

[1] Geol. Survey Ohio, 4th Ser., Bull. 17, p. 65, 1912.

with red or mottled colors. Both the Brush Creek and Cambridge limestones are persistent on the outcrop in this county. In Meigs County where the exposures are confined chiefly to Columbia and Salem townships, sandstone is prominently developed on the Buffalo horizon. In places the member is composed of shaly sandstone and sandy shale. Vinton County, which in part lies west of Meigs County, contains a narrow fringe of Conemaugh rocks along its eastern margin. The distribution of the Buffalo in this area is confined to the summits of the hills and ridges and the areal extent is therefore limited. The material consists of sandstone and sandy shale.

The Buffalo member outcrops in the western part of Athens County where the chief areas of exposure occur in Lee, Waterloo, York, Dover, and Trimble townships. The horizon in this county consists chiefly of sandy shale. Buffalo shale is worked at Nelsonville and utilized extensively at Plants Nos. 1 and 2 of the Nelsonville Brick Company for the manufacture of paving block and fireproofing. As the shale is rather sandy, about 2 per cent of Lower Kittanning clay is added to improve the working properties and to increase the bond. A section of the exposures in the pit is as follows:

	Ft.	In.
Shale, greenish gray, rather sandy, *Buffalo*	35	0
Shale, dark, carbonaceous, fossiliferous, *Brush Creek*	3	0
Shale and covered	75	0
Sandstone, heavy bedded, micaceous	42	0
Shale and covered	10	0
Limestone, nodular, *Upper Freeport*	..	8
Shale, gray, sandy	13	10
Shale, black, carbonaceous	5	0
Coal, *Lower Freeport*	..	4

Buffalo shale from this pit is shipped to Logan where it is used for making paving block at the plant of the Hocking Valley Brick Company. A sample of the 35-foot bed of Buffalo shale shown in the above section was cut on July 15, 1929, and was submitted for testing. The results are as follows:

Sample No. 39

Tests of Buffalo shale from pit of the Nelsonville Brick Company, Nelsonville, Athens County

Chemical analysis — *Downs Schaaf, analyst*

				Oxide ratio			
Water, hydroscopic, H_2O-	1.77						
Water, combined, H_2O+	5.06	K_2O	.132				
Silica, SiO_2	60.42	Na_2O	.019			SiO_2	3.236
Alumina, Al_2O_3	18.67	CaO	.032	Al_2O_3	1.00	TiO_2	0.061
Titanic oxide, TiO_2	1.14	MgO	.117			P_2O_5	0.006
Phosphorus pentoxide, P_2O_5	0.11	FeO	.349				
Ferric oxide, Fe_2O_3	5.77	MnO	.003				
Ferrous oxide, FeO	1.33						
Lime, CaO	0.60	RO	.652				

Magnesia, MgO...........	2.19
Sodium oxide, Na_2O.......	0.35
Potassium oxide, K_2O.....	2.47
Manganese oxide, MnO....	0.05
Sulphur trioxide, SO_3......	0.04
Carbon dioxide, CO_2......	0.10
Carbon, organic, C........	0.12

Physical properties, determined by Chester R. Austin
Properties in green state

Workability: This shale has rather short plasticity. A badly featheredged column is extruded from the die.

Time of slaking: 13.70 minutes.

Water of plasticity: 19.88 per cent.

Dry shrinkage:

Volume: 10.83 per cent.

Linear: 3.49 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 407 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	22.35	9.17	3.0	11.10	2.10	2.61
04	15.92	16.21	4.0	7.37	2.16	2.56
02	12.88	18.78	5.9	5.77	2.25	2.58
1	10.17	20.79	6.5	4.41	2.32	2.58
3	7.80	22.24	6.9	3.29	2.37	2.58
5	2.98	22.80	7.1	1.25	2.38	2.44
7	1.24	21.98	6.8	0.53	2.35	2.38

Fired modulus of rupture:

Cone 05, 1,926 pounds per square inch.

Cone 3, 3,316 pounds per square inch.

Fired specific impact strength:

Cone 05, 1.31 centimeter kilograms per square centimeter.

Cone 3, 1.33 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 3, 13,376 pounds per square inch.

Best firing range: Cone 06 to cone 5.

Overfiring temperature: Cone 7.

Pyrometric cone equivalent: Cone 12.

Scumming: Scum occurs on all trials fired to cone 01 and lower but scum is not apparent on trials fired to cone 3 and above. One pound of $BaCO_3$ per ton of material is required to prevent scumming.

Salt glazing: A good salt glaze is developed at 2,050°F. and at 2,100°F. The color of the glaze produced at both temperatures is a greenish black or gray shading to a reddish brown. When $BaCO_3$ is added a glaze is not produced at 2,100°F.

Utilization: This shale was being utilized for the production of paving brick. It can be used also for face brick and common brick. The fired material has a stony structure. A good red color is developed at cone 01.

Shale, a part of which is Buffalo in age, was formerly used for making paving block by the Trimble Brick Manufacturing Company of

Trimble. A section of the exposures in the pit as described by Condit is given below:[1]

	Ft.	In.
Shale, carbonaceous, with fossils; the place of Portersville limestone and Anderson coal	..	6
Clay, bluish on fresh exposures, reddish on weathered portion	12	0
Sandstone, calcareous, with marine fossils, *Cambridge* horizon	3	0
Shale, sandy, bluish, becoming darker toward the base and having abundant fossil pelecypods and plants, *Brush Creek* horizon	38	0

Buffalo shale has been used likewise at Glouster for making paving brick. The plant was formerly owned by the Wassell Brick Company and later purchased by the Hisylvania Coal Company. In addition to the Buffalo shale, material from both the Brush Creek and Mason horizons has been utilized to some extent at this plant. A description of the rock exposures is given below:

	Ft.	In.
Shale, greenish gray, *Buffalo*	23	0
Shale, dark, carbonaceous, *Brush Creek*	22	3
Sandstone, shaly	4	6
Shale, bluish gray, *Mason*	10	6
Shale, black, carbonaceous, *Mason* coal horizon	..	4
Clay, bluish gray	6	3
Shale, gray, sandy	10	0

A sample of Buffalo shale exposed in this pit with a thickness of 23 feet was secured on July 18, 1929, and was submitted to the laboratories for testing. The results of the various tests are tabulated below:

Sample No. 38

Tests of Buffalo shale from pit of the Hisylvania Coal Company, Glouster, Athens County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.70
Water, combined, H_2O+	5.19
Silica, SiO_2	61.42
Alumina, Al_2O_3	18.08
Titanic oxide, TiO_2	1.31
Phosphorus pentoxide, P_2O_5	0.11
Ferric oxide, Fe_2O_3	6.65
Ferrous oxide, FeO	0.77
Lime, CaO	0.50
Magnesia, MgO	1.72
Sodium oxide, Na_2O	0.22
Potassium oxide, K_2O	2.25
Manganese oxide, MnO	0.06
Sulphur trioxide, SO_3	trace
Carbon dioxide, CO_2	0.02
Carbon, organic, C	0.14

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .124 \\ Na_2O & .012 \\ CaO & .028 \\ MgO & .095 \\ FeO & .374 \\ MnO & .003 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.397 \\ TiO_2 & 0.072 \\ P_2O_5 & 0.006 \end{array}\right.$$

RO .636

[1] Geol. Survey Ohio, 4th Ser., Bull. 17, p. 110, 1912.

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has rather short plasticity. A badly featheredged column is extruded from the die.

Time of slaking: 13.36 minutes.

Water of plasticity: 19.81 per cent.

Dry shrinkage:

Volume: 11.91 per cent.

Linear: 3.83 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 470 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	24.20	11.87	3.8	11.86	2.04	2.69
04	17.71	15.05	4.8	8.34	2.13	2.59
02	14.19	17.81	5.6	6.06	2.22	2.58
1	11.32	20.40	6.3	4.98	2.29	2.58
3	9.10	22.81	7.1	3.90	2.34	2.57
5	6.16	23.40	7.3	2.65	2.36	2.52
7	4.54	23.02	7.2	1.93	2.36	2.31

Fired modulus of rupture:

Cone 02, 2,555 pounds per square inch.

Cone 5, 3,595 pounds per square inch.

Fired specific impact strength:

Cone 03, 1.58 centimeter kilograms per square centimeter.

Cone 4, 1.26 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 5, 14,776 pounds per square inch.

Best firing range: Cone 06 to cone 5.

Overfiring temperature: Cone 7.

Pyrometric cone equivalent: Cone 11-12.

Scumming: Scum occurs on all trials fired to cone 01 and lower but scum is not apparent on trials fired to cone 3 and above. One pound of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: The color of the glaze produced at 2,100°F. is a brownish green on pinkish gray grading into a reddish brown. The color of the glaze produced at 2,050°F. is a reddish brown with some green specks. A fair glaze having a chocolate brown color is produced at 2,100°F. when $BaCO_3$ is added to the material.

Utilization: This material was being utilized for the production of building block and paving brick. Other possible uses are for face brick and common brick. The fired material has a stony structure. A good red color is developed at cone 2.

In Perry County the chief area of exposures of the Buffalo member occurs in Monroe and Bearfield townships where it consists of a sandy shale with a thickness ranging from 20 to 40 feet. The belt of exposures extends east into Morgan County with outcrops in Homer, York, Deerfield, Union, and Bloom townships. The Buffalo horizon is well exposed along the East Branch of Sunday Creek and along the Muskingum River Valley, and consists of sandy shale ranging from 25 to 35 feet in thickness. In places this shale is overlain by the heavy-bedded Cow Run sandstone which has replaced the Wilgus coal and Cambridge limestone.

The Buffalo horizon has little ceramic possibilities in Muskingum County as it is represented chiefly by sandstone. In the southern part of the county, including Clay, Brush Creek, Harrison, Blue Rock, and Salt Creek townships, the material is fine grained and shaly in character, but in the northern part the stone is coarse grained and massive. This massive sandrock phase extends across the western and northwestern parts of Guernsey County.

At Cambridge and immediate vicinity the Buffalo is represented by sandy shale with a thickness of over 40 feet. Sandstone is generally present on this horizon in southeastern Tuscarawas, in western Harrison, and in much of Carroll counties, but in Columbiana County the member is composed almost entirely of shale. Buffalo shale in Columbiana County varies in thickness from 30 to 80 feet, but averages about 60 feet. It is generally gray and siliceous in character. Limestone nodules are entirely wanting and iron ore concretions are relatively few in number. Its distribution above drainage includes parts of Yellow Creek, Washington, Franklin, Wayne, Madison, Liverpool, St. Clair, Middleton, Center, and Hanover townships.

Since 1912 the Brush Creek and Buffalo shales have been used extensively by the Summitville Clay Products Company of Summitville, Franklin Township, for the manufacture of face brick and floor tile. In 1930 red brick was being graded into seven shades. Flash colors were also being produced at this plant. The rock exposures in the pit are described below:

	Ft.	In.
Shale, greenish gray, sandy, *Buffalo*	22	0
Shale, dark blue, sparingly fossiliferous, *Brush Creek*	30	0
Base of pit	..	..

When the pit was visited in 1930 the upper 22 feet of shale was being utilized in the plant, although the Brush Creek shale below had formerly been the source of material. A sample of shale was secured from this pit by A. E. MacGee of the National Bureau of Standards.

Sample No. 208

Tests of Brush Creek and Buffalo shales from the pit of the Summitville Brick Company, Summitville, Columbiana County.

(Tests by the Bureau of Standards)[1]

Chemical analysis		*Oxide ratio*					
Loss on ignition	6.2	K_2O	.14				
Silica, SiO_2	60.8	Na_2O	.04				
Alumina, Al_2O_3	18.0	CaO	.03				
Ferric oxide, Fe_2O_3	7.2	MgO	.08	Al_2O_3	1.00	SiO_2	3.37
Lime, CaO	0.5	FeO	.36			TiO_2	0.06
Magnesia, MgO	1.5						
Titanic oxide, TiO_2	1.0	RO	.65				
Sodium oxide, Na_2O	0.7						
Potassium oxide, K_2O	2.6						
Sulphur, S	0.0						
Total carbon, C	0.6						

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

Physical tests

Tempering water	About 22 per cent
Drying linear shrinkage	About 3 to 4 per cent
Drying volume shrinkage	About 10 to 11 per cent

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	0.3	1.0	17.9	Buff
Cone 06	3.6	10.3	16.0	Reddish buff
Cone 04½	6.1	17.2	8.7	Red
Cone 03	8.1	22.4	7.3	Rich red
Cone 4	9.8	26.7	3.5	Maroon
Cone 7	10.0	27.1	2.2	Maroon

Overburning temperature: Cone 8 (1,225°C. or 2,237°F.).

Best apparent burning range: Cone 04 to cone 4 (1,050°C. to 1,165°C. or 1,922°F. to 2,129°F.).

Total linear shrinkage at cone 7: About 13 to 14 per cent.

Deformation temperature: Cone 11 (1,285°C. or 2,345°F.).

Buffalo shale was formerly used at Salineville to a small extent by the Ohio Clay Products Company, now owned by Strabley & Sons, for the manufacture of drain tile. The shale utilized has a thickness of about 30 feet and lies directly above the Brush Creek member. Here the basal part of the deposit is grayish blue in color and argillaceous in composition, whereas the upper part is gray and somewhat sandy.

In the southern part of West, in Hanover, Center, Elk Run, and Middleton townships, the Buffalo shale outcrops near the crests of the hills and ridges where it has good character and thickness. Areas of variable size are also found near the crests of the ridges in St. Clair Township. Along the valleys of West Fork of Little Beaver and North Fork of Yellow Creek, this shale is of good thickness and quality, but it outcrops at somewhat lower elevations. The following measurements are from the west central part of Section 17, Madison Township:[1]

		Ft.	In.
Shale, dark gray, *Buffalo*		45	0
Shale, black, fossiliferous	*Brush Creek*	18	0
Limestone, black, fossiliferous	*Brush Creek*	1	0
Shale, dark, fossiliferous	*Brush Creek*	9	8
Coal, shaly, *Brush Creek*		..	4

In Jefferson County the Buffalo member is above drainage in parts of Saline, Brush Creek, Springfield, Ross, Knox, Island Creek, and Steubenville townships. Throughout the northern part of the county the member consists in general of gray sandy shale, although in places a few thin layers of sandstone are interstratified with the shale. At a few places

[1] Geol. Survey Ohio, 4th Ser., Bull. 28, p. 327, 1924.

in Springfield and Saline townships, beds of soft red shales are present on this horizon. Along the Ohio River Valley in the southern part of Island Creek and northern Steubenville townships this shale is replaced by massive sandstone. The average thickness of the Buffalo shale in Jefferson County is about 50 feet. Both shale and sandstone are shown in the following record of exposures near Stanton Park in Section 21, Island Creek Township.

		Ft.	In.
Limestone, fossiliferous, *Cambridge*		1	2
Shale, with limestone nodules		8	2
Shale, green, arenaceous	*Buffalo*	2	6
Sandstone, coarse-grained		10	4
Shale, gray to dark, arenaceous		29	0
Shale, fossiliferous, with ore nodules, *Brush Creek*		6	10
Shale, dark		1	4
Shale, bony, with shaly coal		..	11
Parting	*Brush Creek*	..	1
Coal		..	6

Shales Between the Cambridge and Ames Limestones

In Ohio the rocks occupying the interval between the Cambridge and Ames limestones consist chiefly of shale and sandstone with a few thin beds of coal, clay, and limestone, which are of slight economic importance. The thickness of this series, which outcrops across the southeastern part of the State from Lawrence and Gallia counties on the south to Columbiana and Jefferson counties on the east, is quite variable but averages about 95 feet. The succession of members in descending order is as follows:

Ames limestone
Harlem shale
Harlem coal and clay
Round Knob shale
Saltzburg sandstone
Barton coal
Ewing limestone
Cow Run shale and sandstone
Portersville limestone and shale
Anderson coal
Wilgus shale
Cambridge limestone

In localities where the complete sequence of beds is represented the series between the Cambridge and Ames limestone consists of four distinct shale horizons separated by thin coal and clay beds. The Wilgus and Cow Run horizons are separated by the Anderson coal and clay and overlying Portersville limestone and shale beds. The Anderson horizon is of wide extent on the outcrops in Ohio, but the coal is best developed in Guernsey, Muskingum, Morgan, Perry, and Athens counties. In a few localities in the first three counties named the coal is of minable thickness. It is overlain by the Portersville beds, which consist of dark, fossiliferous shale with nodular limestone embedded in it in some localities. The Portersville is discontinuous in extent, but is best developed in Morgan, Muskingum, Guernsey, and Harrison counties, where it is only a few feet in thickness. The Barton coal and its underlying clay are of slight importance as the coal is too thin to mine except in parts of Carroll County and the clay is everywhere calcareous and impure. The Ewing limestone, which is of the fresh water type, occurs embedded in the Barton clay. In some localities where the clay and coal are wanting the Ewing horizon is represented by a few feet of calcareous shale with nodules of impure limestone.

The Harlem coal and clay horizon is not well represented south of Morgan County, but north of this area the coal is a rather persistent stratigraphic horizon and is a local source of fuel in parts of Muskingum and Carroll counties. As the coal, clay, and limestone members between the Cambridge and Ames limestones lack continuity as stratigraphic horizons and as the shale members in this interval are of slight economic importance, the beds will be considered together in the following discussion.

Areal Distribution and Character

In Lawrence County the beds between the Cambridge and Ames limestones outcrop in a north and south belt extending from Fayette and Union townships north through Mason, Aid, and Symmes townships. The series consists chiefly of shale, a large part of which is of a red or mottled color. The Ames limestone is generally wanting in this county, but it is present a little west of Huntington, West Virginia. The Harlem and Round Knob shales are the source of materials used by the Huntington Brick and Tile Company and the Huntington Paving Brick Company, both located at Huntington. In Lawrence County the beds above the Cambridge limestone outcrop along the lower course of Symmes Creek in Union Township. A section of the exposures about one mile from the mouth of the stream is as follows:

	Ft.	In.
Shale, greenish gray, sandy	16	0
Shale, soft, mottled, greenish, gray, red	3	0
Shale, greenish gray, a little sandy	4	0
Shale, soft, mottled gray and red	6	4
Shale and covered	44	0
Limestone, dark, *Cambridge*	1	10
Shale, dark, bluish	10	0
Water level, Symmes Creek	..	..

The beds described in the upper part of this section and having a combined thickness of 29 feet 4 inches were sampled on June 27, 1929, for chemical analysis and other tests. The results of the various tests are tabulated below:

Sample No. 40

Tests of Conemaugh shale from outcrops near Chesapeake, Lawrence County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.95
Water, combined, H_2O+..	5.50
Silica, SiO_2...............	56.30
Alumina, Al_2O_3............	20.96
Titanic oxide, TiO_2........	1.05
Phosphorus pentoxide, P_2O_5	0.20
Ferric oxide, Fe_2O_3........	3.65
Ferrous oxide, FeO........	2.07
Lime, CaO................	1.82
Magnesia, MgO...........	2.05
Sodium oxide, Na_2O.......	0.44
Potassium oxide, K_2O.....	2.93
Manganese oxide, MnO....	0.06
Sulphur, S................	0.01
Carbon dioxide, CO_2.......	1.16
Carbon, organic, C........	0.02

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .140 \\ Na_2O & .021 \\ CaO & .087 \\ MgO & .098 \\ FeO & .255 \\ MnO & .003 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 2.686 \\ TiO_2 & 0.050 \\ P_2O_5 & 0.009 \end{array}\right.$$

$$RO \quad .604$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workabililty: This material has rather short plasticity. A badly featheredged column is extruded from the die.

Time of slaking: 19.45 minutes.

Water of plasticity: 16.83 per cent.

Dry shrinkage.

Volume: 11.03 per cent.

Linear: 3.55 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 280 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	19.10	11.55	3.7	8.91	2.14	....
04	13.07	16.05	5.1	5.82	2.24	2.58
02	10.50	17.72	5.6	4.72	2.30	2.57
1	8.66	19.05	6.0	3.75	2.34	2.61
3	7.09	18.97	6.0	2.99	2.36	2.60
5	5.08	17.82	5.6	2.17	2.35	2.47
7	6.01	17.26	5.5	2.65	2.27	2.42

Fired modulus of rupture:

Cone 05, 2,098 pounds per square inch.

Cone 5, 3,260 pounds per square inch.

Fired specific impact strength:
Cone 05, 1.60 centimeter kilograms per square centimeter.
Cone 4, 1.31 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 4, 10,620 pounds per square inch.
Best firing range: Cone 06 to cone 4.
Overfiring temperature: Cone 5.
Pyrometric cone equivalent: Cone 11.

Scumming: Scum occurs on all trials fired to cone 2 but scum is not apparent on trials fired above cone 2. One pound of $BaCO_3$ per ton of material is required to prevent scumming.

Salt glazing: A good salt glaze is produced at 2,050°F. and at 2,100°F. The color of the glaze produced at both temperatures is a reddish brown with a yellow mottle. A glaze is not developed when $BaCO_3$ is added to the material.

Utilization: This shale was not being utilized for ceramic purposes. Its physical properties suggest that this shale can be utilized for the production of face brick, common brick, and possibly for paving brick. The fired material has a stony structure. A good red color is developed at cone 04.

In Gallia County the chief area of exposure of the beds between the Cambridge and Ames limestones lies in Morgan, Raccoon, Walnut, Perry, and Green townships. In this county soft red and mottled shales with nodular masses of limestone embedded in them are prominently developed. Massive sandstone between the Ames and Cambridge horizons is generally wanting but in places thin beds of gray sandy shale and shaly sandstone are present. The following record which was measured by Wilber Stout in Section 34, Morgan Township, is in general representative.

	Ft.	In.
Limestone, *Ames*	2	0
Shale, gray	18	0
Shale, soft, red	15	0
Shale, gray	9	0
Shale, soft, red	10	0
Shale, sandy	4	0
Sandstone, shaly	6	0
Covered interval	16	0
Limestone, *Cambridge*	2	0

Throughout the western part of Meigs County soft red shales are conspicuous between the Cambridge and Ames limestones. Such shales are ferruginous and generally highly calcareous. At a few localities in Salem Township the Cow Run horizon is represented by massive sandstone. The character of these beds is similar in the outcrop areas in western Athens County. The Round Knob horizon is generally represented by soft shales of red or mottled hues and the Cow Run member is generally a gray sandy shale, although in places along the Sunday Creek Valley and its tributaries it is represented by massive sandstone. Shale between the Portersville and Ames limestones was formerly utilized at Athens by the Athens Brick Company. Paving block was the chief product of this plant. The rocks exposed in the pit are typical for these beds in Athens County. They are described in the following section:[1]

	Ft.	In.
Limestone, many fossils, exposed at south end of cliff, *Ames*	1	8
Clay, deep red color, nodular limestone in lower portion	24	0
Shale, sandy, bluish gray color, with reddish brown bands in lower portion. Fossil, ripple marks and sun cracks along the bedding planes	33	0
Limestone, fossiliferous, *Portersville*	..	5
Shale, carbonaceous, many fossils	3	0

In Perry County exposures of the beds between the Cambridge and Ames horizons are found chiefly in Monroe and Bearfield townships along the eastern border. The belt extends into western Morgan County where outcrops are found in Homer, Union, Deerfield, York, and Bloom townships. Here the Round Knob member consists of both the soft red shale and the gray sandy varieties. The Cow Run member is represented by massive sandstone along the Muskingum Valley in Bloom Township. Sandstone is also prominently developed on the Cow Run horizon in Harrison and Blue Rock townships, Muskingum County, and is locally developed in Brush Creek, Salt Creek, Wayne, Union, Salem, and Highland townships. In some localities sandy shale and shaly sandstone are present. The Round Knob horizon in Muskingum County is occupied chiefly by gray sandy shale and shaly sandstone. The Harlem member in this county likewise consists of sandy shale and shaly sandstone. The following record of exposures one mile northwest of Norwich in Union Township is representative:[2]

	Ft.	In.
Limestone, in two layers, upper one gray and pure; lower one sandy and impure. Fossils are abundant, *Ames*	3	6
Shale, *Harlem*	20	0
Coal, thickness approximate, *Harlem*	2	0
Shale, sandy	62	0
Shale, dark, many fossils preserved as pyrite, *Portersville* horizon	3	0
Coal, thickness approximate, *Anderson*	2	0
Clay, with nodules of limestone	12	0
Limestone. A number of irregular layers, some of which are flint. Fossils are abundant. The limestone decays to a soft, brown, porous rock, *Cambridge*	4	0

The best exposures of the beds between the Cambridge and Ames limestones in Noble County are confined to the valley of Duck Creek and its tributaries in Buffalo and Noble townships. Shales above the Anderson coal have been utilized for a number of years near Ava, for the manufacture of face brick. The plant is located at the southern edge of Section 30, Buffalo Township, about 1½ miles north of town. It was formerly

[1] Geol. Survey Ohio, 4th Ser., Bull. 17, p. 114, 1912.
[2] Idem., p. 149.

owned and operated by the Noble Brick Company, but in recent years has been doing business under the name of the Ava Brick Company. A description of the beds exposed near the plant is as follows:

		Ft.	In.
Shale, greenish gray, sandy	*Cow Run*	26	0
Shale, bluish gray, a little sandy	*Cow Run*	6	2
Covered interval		15	6
Coal, *Anderson*		1	4
Clay, gray, plastic		1	4
Clay, sandy		1	4
Limestone, *Cambridge*		1	2

The shale utilized has a thickness of about 32 feet. Mr. A. E. MacGee of the National Bureau of Standards secured a sample of shale from this pit for testing.

Sample No. 209
Tests of Cow Run shale from the pit of the Ava Brick Company, near Ava, Noble County.
(Tests by the Bureau of Standards)[1]

Chemical analysis

Loss on ignition	7.6
Silica, SiO_2	60.5
Alumina, Al_2O_3	17.1
Ferric oxide, Fe_2O_3	7.1
Lime, CaO	1.4
Magnesia, MgO	1.8
Titanic oxide, TiO_2	1.0
Sodium oxide, Na_2O	0.5
Potassium oxide, K_2O	2.5
Sulphur, S	0.0
Total carbon, C	0.3

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .15 \\ Na_2O & .03 \\ CaO & .08 \\ MgO & .10 \\ FeO & .37 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.53 \\ TiO_2 & 0.06 \end{array}\right.$$

RO .73

Physical tests

Tempering water:	About 20 per cent.
Drying linear shrinkage:	About 4 to 5 per cent.
Drying volume shrinkage:	About 15 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	1.8	5.3	13.6	Brick red
Cone 06	6.4	18.1	7.5	Light red
Cone 04	7.7	21.3	3.5	Reddish brown
Cone 3	4.2	12.0	1.1	Rich red

Overburning temperature: Cone 4 (1,165°C. or 2,129°F.).

Best apparent burning range: Cone 06 to cone 2 (1,005°C. to 1,135°C. or 1,841°F. to 2,075°F.).

Total linear shrinkage at cone 04: About 12 to 13 per cent.

Deformation temperature: Cone 10 (1,260°C. or 2,300°F.).

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

North of Noble County the beds occupying the Cambridge-Ames interval outcrop over a narrow belt extending across the east central part of Guernsey County, where they consist of gray sandy shale and shaly sandstone. They also appear above drainage along the valley of Stillwater Creek in the northwestern corner of Belmont County, but their areal extent is small. These beds cap the highest hills and ridges in the southeastern corner of Tuscarawas County. In Harrison County beds between the Cambridge and Ames limestones are widely distributed at the surface as they outcrop along the valleys of Stillwater Creek, Little Stillwater Creek, and Conotton Creek. The series consists chiefly of sandy shale with minor amounts of the soft red or pink varieties. The Anderson and Harlem coals are of wide extent, but they are too thin for profitable mining.

The shale members have much the same features in Carroll County where the chief areas of outcrop occur in Perry, Union, Lee, and Loudon townships. The following is a description of exposures in Section 20, Loudon Township:[1]

	Ft.	In.
Limestone, rusty gray, crystalline rock with many crinoid fragments and brachiopod shells, *Ames*	1	6
Clay, red, interlain with shale; slips are common at this horizon, *Round Knob*	62	0
Shale, sandy, yellowish-gray	53	0
Shale with concretions of yellow limestone	10	0
Limestone, impure, blocky. Brachiopods and other marine fossils, *Cambridge*	..	10

The Harlem coal, although not shown in the section above, is in general persistent throughout the county. Near Harlem Springs, where it reaches thicknesses of 2 or even 4 feet, this bed has been a local source of fuel for many years. At places in Union Township the Round Knob shales are replaced by massive sandstone.

In Columbiana County the strata lying between the Cambridge and Ames limestones outcrop near the summits of the hills and ridges in Franklin, Wayne, Madison, Washington, and Yellow Creek townships. The beds consist chiefly of shale, although some shaly sandstone is present. The total average thickness is about 115 feet. Soft red calcareous shale is prominently developed on the Round Knob horizon over much of the area. Similar material is also present in some localities above the Harlem coal. The shale on the Cow Run horizon is generally of the gray sandy type which in places grades into shaly sandstone. In Jefferson County the beds in the Cambridge-Ames interval outcrop along the Ohio River and its tributary valleys as far south as the mouth of Short Creek in Warren Township. At the north edge of the county these strata outcrop near the crests of the ridges, but due to the inclination

[1] Geol. Survey Ohio, 4th Ser., Bull. 17, p. 214, 1912.

of the beds they appear at progressively lower levels to the southward. In this county shale is the chief type of rock on the Harlem and Round Knob horizons. The soft, red, calcareous types characterize the Round Knob in much of Springfield Township and along Croxton Run in Knox Township. The gray sandy types are found elsewhere on this horizon in Jefferson County. Sandy shale is also the predominating type on the Cow Run horizon although sandstone is locally present in Brush Creek, Springfield, Island Creek, Knox, and Steubenville townships. The following record from Section 32, Knox Township, is in general representative for the county.

		Ft.	In.
Limestone, *Ames*		1	6
Shale and covered, *Harlem*		20	8
Clay, light, arenaceous, *Harlem* coal horizon		4	6
Shale, red, *Round Knob*		7	10
Limestone, nodular	*Ewing*	..	3
Clay with limestone nodules	*Ewing*	6	0
Shale and covered	*Cow Run*	6	9
Sandstone	*Cow Run*	21	2
Shale, red	*Cow Run*	22	10
Coal blossom, *Anderson*		..	1
Clay, mottled		4	6
Shale, gray to red, *Wilgus*		15	2
Limestone, nodular, *Cambridge*		..	2

Conemaugh Shales Above the Ames Limestone

The Conemaugh series above the Ames limestone consists of beds of sandstone, shale, limestone, coal, and clay, all of which tend to be variable in character on the outcrop and none of which is of great economic importance. This series has an average thickness of nearly 200 feet in Ohio. It outcrops over a belt of variable width extending across the southeastern part of the State from Jefferson and Belmont counties on the east to Lawrence, Gallia, and Meigs counties on the south. The chief members of this series are given below, the oldest appearing at the bottom and the youngest at the top.

Upper Pittsburgh limestone
Upper Little Pittsburgh shale
Upper Little Pittsburgh coal
Bellaire sandstone and shale
Lower Little Pittsburgh coal
Summerfield shale
Summerfield limestone
Connellsville shale and sandstone
Clarksburg coal
Clarksburg limestone
Morgantown sandstone and shale

Elk Lick coal
Elk Lick limestone
Birmingham shale
Skelley limestone
Duquesne coal
Ames shale
Ames limestone

It has not been the practice in geological literature to apply names to shale beds of the Pennsylvanian system, but for convenience in description in this report, the name of a coal bed is generally applied to the shale which closely overlies it, except where a prominent sandstone which has been named occurs on the same horizon. In this case the term applied to the sandstone is also used for its corresponding shale facies. Some variation from this method is necessary in parts of the column. Thus the Ames limestone, which is one of the most persistent beds of the Conemaugh series, separates the shale interval between the Harlem and Duquesne coals into two parts. That part lying above the Ames is then called the Ames shale and the term Harlem is restricted to the portion below the limestone. A similar condition occurs with respect to the Summerfield shale, the term Summerfield being used for the part above the limestone. Terms applied to shale beds are used for convenience in description only.

The chief characteristic of the coal, clay, and limestone of the Conemaugh series above the Ames is their lack of continuity. The Skelley member, which normally lies about 37 feet above the Ames, is generally represented by only a few inches of fossiliferous shale or limestone. It is probably best developed in Jefferson County, but the member has been found along the outcrop as far southwest as Morgan County. In Jefferson County the Skelley horizon carries a thin coal below it known as the Duquesne coal. The Elk Lick coal and limestone are found chiefly in Jefferson County, where they are generally thin. The limestone is of the fresh water variety and is usually found embedded in the materials closely underlying the coal. Much the same conditions of poor development and irregular distribution characterize the Clarksburg coal and closely underlying Clarksburg limestone. One or both have been recognized in Jefferson, Harrison, Muskingum, Meigs, and Athens counties, but the beds are by no means continuous over these areas.

The Summerfield or Lower Pittsburgh limestone which is of the fresh water type generally consists of several layers of stone separated by calcareous shale partings of variable thickness. Like all limestones of this origin, it is patchy in distribution and uneven in thickness. It has been identified at many places from Jefferson southwest to Morgan County in which area it averages about 12 feet in thickness. Its average position is about 45 feet below the Pittsburgh coal. Both the Upper and Lower Little Pittsburgh coals are thin and are seldom present on the outcrop. The Pittsburgh limestone is like the Summerfield in its general stratigraphic features. It has been recognized at various places as far south as Meigs County.

The shale beds of the Conemaugh series above the Ames limestone make up a large part of the total thickness of this series. They are generally calcareous and therefore poorly adapted to the manufacture of high-grade brick or tile. The distribution and general features of these beds on the outcrop areas are discussed briefly below.

Character and Areal Distribution

The Conemaugh beds above the Ames limestone outcrop along a north and south belt extending through the eastern part of Lawrence County, where they are represented chiefly by sandstone and shale. Sandstone is prominently developed on both the Morgantown and Connellsville horizons in this county. The shales include both the sandy and soft red varieties, the latter being calcareous and ferruginous in character. Much the same conditions occur in Gallia County where exposures are found in every township with the possible exception of Huntington, Raccoon, and Greenfield in the northwestern and western parts. The shales are chiefly of the calcareous and ferruginous types. The following section secured near Northrup, Green Township, is in general representative:[1]

	Ft.	In.
Coal horizon, *Pittsburgh*	..	..
Shale, with limestone nodules	24	0
Sandstone	4	0
Shale, bluish	3	0
Clay, with limestone nodules	12	0
Shale, red	30	0
Sandstone	4	0
Shale, soft, red	5	0
Shale, soft, bluish	2	0
Sandstone	9	0
Shale, soft, red	4	0
Sandstone, not well shown	9	0
Shale, red	10	0
Sandstone, shaly	3	0
Shale, soft, red, with nodular limestone	29	0
Sandstone, shaly	9	0
Shale, calcareous, probable place of *Ames* limestone	13	0

In the western part of Meigs County the Conemaugh series above the Ames limestone is characterized by much red shale and sandstone having an average combined thickness of about 155 feet. The Morgantown

[1] Geol. Survey Ohio, 4th Ser., Bull. 17, p. 86, 1912.

horizon is marked by much sandstone as is also the Connellsville along Leading Creek Valley. Near Pagetown in Scipio Township the Ames horizon is overlain by about 90 feet of shale which is chiefly of the soft red variety. Much the same type of rocks are found above the Ames in the vicinity of Hanesville in the southeastern corner of Salem Township. In Athens County the belt of exposures extends from Lodi, Alexander, and Lee townships on the south to Bern, Ames, and Dover townships on the north. Here the Conemaugh beds above the Ames present much the same aspects as in the outcrop areas farther south. Sandstone is prominently developed on the Connellsville horizon at Athens and along the valleys to the eastward. Above and below the sandstones are calcareous and ferruginous shales. Shale overlying the Ames limestone formerly supplied a part of the raw materials used at the plant of the Athens Brick Company of Athens which has been abandoned. The following description of exposures in the pit is rather typical for these beds in Athens County:[1]

	Ft.	In.
Sandstone	20	0
Shale, red and bluish gray, changing from sandy in upper portions to calcareous near base	39	0
Limestone, *Ames*, many fossils. Exposed at south end of cliff	1	8
Shale, soft, deep red color, nodular limestone in lower portion	24	0
Shale, sandy, bluish gray color, with reddish brown bands in lower portion. Fossil, ripple marks and sun cracks along the bedding planes	33	0
Limestone, fossiliferous, *Portersville*	..	5
Shale, carbonaceous, many fossils	3	0

Shale below the Ames limestone was also formerly used at this plant. From Athens County the exposures of Conemaugh beds above the Ames limestone extend northeast through the central part of Morgan County, where they are represented chiefly by shale and shaly sandstones. The shale is in large part of the soft, red, calcareous type with small nodules of impure limestone. The Morgantown horizon is generally represented by shaly sandstone, whereas sandy shale predominates on the Connellsville. The average thickness of this series above the Ames limestone in Morgan County is about 165 feet. The beds have much the same characteristics in Perry County where the areal distribution is limited to the southeastern corner.

The Conemaugh series above the Ames limestone outcrops over a large area in Muskingum County, as exposures occur in every township east of the Muskingum River with the exception of Monroe, Adams, and Madison, and in Brush Creek and Harrison townships west of the river. Soft red calcareous shale is a prominent type in this area. In many places shale of this character extends from a few feet above the Ames limestone

[1] Geol. Survey Ohio, 4th Ser., Bull. 17, p. 114, 1912.

to the horizon of the Summerfield limestone, a vertical distance of about 100 feet. Sandstone is prominently developed in some localities a short distance above the Ames limestone and a short distance below the Pittsburgh coal horizon. The following record from Section 14, Blue Rock Township, is in general representative:

	Ft.	In.
Coal blossom, *Pittsburgh*	..	6
Shale, soft	7	6
Limestone, light in color	1	0
Shale, soft, red, calcareous	21	0
Limestone, light in color	..	8
Shale, soft, red, calcareous	5	4
Limestone, nodular, siliceous	2	0
Shale, soft, red, calcareous, with a few short covered intervals	104	0
Shale, gray, with thin sandstone	13	6
Limestone, siliceous, ferruginous, fossiliferous	1	0
Shale and shaly sandstone	12	6
Limestone, two beds, *Ames*	2	8

From eastern Muskingum County the belt of exposures of Conemaugh beds above the Ames limestone extends through southern and eastern Guernsey County, where the strata are chiefly calcareous, ferruginous shale with some shaly sandstone. Much the same conditions prevail in northern and central Noble County where outcrops cover a large area along Duck Creek and its tributary valleys. The upper part of the series is at the surface over small areas in the northwestern corner of Monroe and along Duck Creek and the Little Muskingum River in Washington County. In Belmont County the upper part of the Conemaugh series outcrops in Flushing, Kirkwood, Warren, and Union townships, in the northwestern corner and along the Ohio River and its larger tributary valleys in the northeastern quarter. Along Wheeling Creek the exposures extend from the Harrison County line to the Ohio River. At McClainville, on McMahon Creek about three miles west of Bellaire, the shale beds lying below the Bellaire sandstone are being utilized for the manufacture of common brick by the Standard Stone and Brick Company. The capacity of the plant is about 45,000 brick a day. Much of the product is sold in Steubenville and Bellaire. A description of the exposures in the pit near the plant is given below:

		Ft.	In.
Sandstone, bluish gray, coarse grained, *Bellaire*		21	9
Clay shale, bluish gray, siliceous	*Summerfield*	2	2
Clay shale, bluish, sandy	*Summerfield*	6	8
Limestone, variable in thickness, *Summerfield*		..	8
Shale, reddish brown, calcareous, with nodules of limestone	*Connellsville*	8	9
Shale, greenish gray, calcareous	*Connellsville*	2	0
Sandrock, bluish, calcareous	*Connellsville*	..	10
Shale, greenish gray	*Connellsville*	..	10
Shale, soft, reddish brown	*Connellsville*	..	6
Shale, greenish gray, calcareous, a little sandy	*Connellsville*	14	0

The material is delivered to the plant in the proportions in which it comes from the shovel. Limestone blocks from the Summerfield horizon are discarded. The beds exposed in this pit below the Bellaire sandstone were sampled for testing on July 23, 1929. The results of the tests are given below:

Sample No. 41

Tests of Summerfield and Connellsville shales from pit of the Standard Stone & Brick Company, McClainville, Belmont County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.51
Water, combined, H_2O+	5.02
Silica, SiO_2	54.86
Alumina, Al_2O_3	17.22
Titanic oxide, TiO_2	0.95
Phosphorus pentoxide, P_2O_5	0.10
Ferric oxide, Fe_2O_3	5.16
Ferrous oxide, FeO	3.40
Lime, CaO	3.64
Magnesia, MgO	1.81
Sodium oxide, Na_2O	0.30
Potassium oxide, K_2O	2.07
Manganese oxide, MnO	0.07
Sulphur trioxide, SO_3	0.09
Carbon dioxide, CO_2	3.77
Carbon, organic, C	0.19

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .120 \\ Na_2O & .017 \\ CaO & .212 \\ MgO & .105 \\ FeO & .467 \\ MnO & .004 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.186 \\ TiO_2 & 0.055 \\ P_2O_5 & 0.005 \end{array}\right.$$

RO .925

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: The plasticity of this material is above the average. A very good column is extruded from the die.

Time of slaking: 83.73 minutes.

Water of plasticity: 17.58 per cent.

Dry shrinkage

Volume: 13.88 per cent.

Linear: 4.43 per cent.

Drying behavior: This material dries satisfactorily with ordinary care.

Dry modulus of rupture: 471 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	16.99	11.13	3.6	8.03	2.11	2.54
04	13.89	13.92	4.4	6.36	2.19	2.54
02	12.98	14.79	4.7	5.87	2.22	2.55
1	11.33	16.12	5.1	5.05	2.25	2.54
3	8.93	17.91	5.6	3.90	2.28	2.51
5	4.94	17.47	5.5	2.16	2.29	2.41
7	7.82	10.40	3.3	3.71	2.11	2.29

Fired modulus of rupture:
Cone 02, 3,427 pounds per square inch.
Cone 3, 3,558 pounds per square inch.
Fired specific impact strength:
Cone 03, 1.72 centimeter kilograms per square centimeter.
Cone 3, 1.26 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 3, 10,133 pounds per square inch.
Best firing range: Cone 06 to cone 4.
Overfiring temperature: Cone 6.
Pyrometric cone equivalent: Cone 9.

Scumming: Scum occurs on all trials fired to cone 3 and lower but scum is not apparent on trials fired above cone 3. Trials fired to cones 3 and 5 show white lime spots on the surface. One pound of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: A good salt glaze is produced at 2,100°F. and at 2,050°F. The color produced at both temperatures is a dark yellow green and reddish brown mottle, the brownish shade being somewhat lighter at 2,050°F. A salt glaze is not produced at 2,100°F. when $BaCO_3$ is added to the material.

Utilization: This shale was being utilized for the production of common brick. As the material has good plasticity it can probably be used for hollow tile and drain tile providing the limestone nodules are removed. The fired material has a stony structure. A good red color is developed at about cone 02.

Throughout the outcrop areas in Harrison County, which include much of the eastern, central, and south central parts, massive sandstone is developed on the Morgantown horizon, while the rest of the series under discussion here is chiefly shale of the calcareous and sandy varieties. Some limestone is present on the Skelley, Summerfield, and Upper Pittsburgh horizons. Similar conditions exist in southern Carroll County. In Columbiana County the outcrops of this series are relatively unimportant as the Ames limestone which marks its base is found only in the highest parts of Franklin, Wayne, Madison, Washington, and Yellow Creek townships. Beds of Conemaugh age above the Ames limestone horizon are widely distributed in Jefferson County as outcrops occur in practically every township. Here the series is characterized chiefly by gray sandy shale and sandstone with minor amounts of calcareous shale and limestone. Shale lying close above the Ames limestone was formerly the source of material supplying the plant of the Walker Brick and Tile Company, located at Dillonvale in Mount Pleasant Township. The plant has been abandoned for several years. The following is a description of the exposures in the pit near the plant:

		Ft.	In.
Shale, greenish, very sandy		15	0
Shale, dark gray, sandy		2	6
Shale, red to reddish brown		13	10
Shale, gray, soft		2	0
Shale, bony	*Elk Lick*	..	5
Coal, bony	*Elk Lick*	..	2
Clay, bluish gray, short		8	10
Clay, red		2	0
Shale, soft, red		16	6

MONONGAHELA SERIES[1]

The Monongahela is the topmost series of the Pennsylvanian system in Ohio. It outcrops over a narrow belt 5 to 15 miles in width which extends across the southeastern part of the State from Jefferson and Belmont counties on the east to Lawrence and Gallia counties on the south. In addition to those divisions already cited, exposures are found in Harrison, Guernsey, Noble, Monroe, Muskingum, Morgan, Washington, Athens, and Meigs counties. The total area of the outcrops of the series in Ohio is about 1,213 square miles. The thickness varies from 240 to 270 feet and the average is about 248 feet. Like the other series of the Pennsylvanian system, the Monongahela is composed of beds of shale, sandstone, limestone, clay, and coal, but the shale, sandstone, and limestone make up over 95 per cent of the group. The chief economic possibilities of the Monongahela series rest in its coal and limestone. The clays of this series are generally thin and impure and the shales are usually too calcareous to yield a good ceramic product. The following table shows the succession of members of the Monongahela series in Ohio and the average thickness of each. The oldest appears at the bottom and the youngest at the top of the list.

Generalized Section of the Monongahela Series of Ohio

Series	Member	General description	Thickness Ft.	In.
Monongahela	Waynesburg, No. 11	Coal, fair purity	1	4
	Gilboy	Shale and sandstone	14	6
	Little Waynesburg	Coal, persistent	..	2
	Waynesburg	Limestone and marly shale	10	0
	Uniontown	Sandstone and shale	28	7
	Uniontown, No. 10	Coal	..	10
	Uniontown	Limestone and shale	5	0
	Arnoldsburg	Sandstone and shale	8	0
	Arnoldsburg	Coal, wanting	..	..
	Arnoldsburg	Limestone and shale	37	0
	Fulton	Shale, green	4	0
	Benwood	Limestone and calcareous shale	34	4
	Sewickley	Sandstone, local, and shale	20	0
	Sewickley, Meigs Creek, No. 9	Coal	1	10
	Fishpot	Sandstone and shale	22	6
	Fishpot	Coal, thin, persistent	..	7
	Fishpot	Limestone and calcareous shale	32	1
	Pomeroy	Sandstone, generally wanting	..	..
	Redstone or Pomeroy	Coal, unsteady	1	4
	Redstone	Limestone and marly shale	13	0
	Upper Pittsburgh	Sandstone, local, and shale	9	0
	Pittsburgh	Coal, persistent	3	7

[1] Much of the data given here is deduced from unpublished notes of Wilber Stout, State Geologist, and field assistants.

The base of the Monongahela series is marked by the important Pittsburgh or No. 8 coal and the top by the Waynesburg or No. 11 coal. This series contains seven distinct horizons where shale beds occur at various localities on the outcrop, namely the Upper Pittsburgh, Fishpot, Sewickley, Fulton, Arnoldsburg, Uniontown, and Gilboy. Sandstones occur on all of these horizons, some local in development and others are more widespread in their distribution. The Upper Pittsburgh, Sewickley, Arnoldsburg, and Uniontown shales are of both the gray sandy varieties and the buff and reddish calcareous types. The Fulton is characteristically a light to dark olive green sandy, calcareous shale a few feet in thickness, while the Fishpot is generally gray to dark in color and sandy in character. The Gilboy horizon is in most places represented by both soft and gray sandy shale with occasional lenses of shaly sandstone. The limestones of the Monongahela series, which are all of the fresh water type, appear massive in places, but the usual mode of occurrence is layers of stone interbedded with calcareous shale. The limestone members are unsteady in horizontal extent. They are replaced locally by sandstone, but where the limestone disappears from the section its place is usually occupied by calcareous shale. In general the shales of the Monongahela series are not well adapted to the production of high grades of brick or tile and to the writer's knowledge are not utilized at any place in this State for such purposes. The general features of areal distribution and character on the outcrop are considered in the following paragraphs.

Areal Distribution and General Character

The lower part of the Monongahela series caps the high hills and ridges in Mason, Windsor, Union, Fayette, and Rome townships in the eastern part of Lawrence County, but the total area is small. The belt of exposures extends north through eastern Gallia County, but the largest area is found in Ohio, Guyan, Clay, and Harrison townships in the southeastern corner. Throughout Green, Gallipolis, Addison, and Cheshire townships the areas are small as the outcrops are found capping the crests of the highest hills. The entire thickness of the series is above drainage through the central part of Meigs County, but some part of the series outcrops in every township except Columbia in the northwest corner. In the western part of the county the lower part of the Monongahela series outcrops as isolated patches or outliers on the high elevations, but due to the eastern inclination of the strata these beds soon pass under cover and the upper part of the series is at drainage level in the eastern part of the county. The Upper Pittsburgh horizon in this county is represented chiefly by soft shale. Above the Pomeroy coal there is a thick sandstone which in Bedford Township reaches a thickness of 75 to 80 feet. Pink and gray shale predominates above this sandstone. The following record was secured by Wilber Stout in Section 26, Bedford Township:

	Ft.	In.
Coal horizon, *Waynesburg*	..	..
Shale, gray, with iron ore nodules	1	6
Shale, gray, and shaly sandstone	15	4
Coal horizon, *Lower Waynesburg*	..	..
Shale, soft, gray	3	0
Covered	14	2
Sandstone, shaly	5	0
Shale, gray, sandy	18	8
Smut streak, *Uniontown*	..	1
Shale, pink, with short, covered intervals	76	3
Sandstone, shaly, gray	7	0
Sandstone, soft, cross-bedded	76	3
Shale, gray, sandy	..	2
Coal, *Pomeroy*	1	4½
Shale, dark	..	6
Shale, gray, and covered	25	8
Coal blossom, *Pittsburgh*	..	7

Athens County, which lies just north of Meigs, contains a large area of Monongahela rocks exposed over much of the eastern half. Gray sandy shales are generally present on the Upper Pittsburgh horizon, although sandstone is strongly developed at places in the central part of the county. The Sewickley and Uniontown horizons are likewise predominantly shale. The pink and red calcareous varieties are widely distributed in this county between the Pomeroy and Uniontown coal horizons. In Washington County the total area of Monongahela exposures is not large, although the top of the series is above drainage along West Branch of Little Hocking, the Muskingum River Valley, along Duck Creek nearly to the Ohio River, along much of the Little Muskingum Valley in this county, and along the Ohio Valley northeast of Waverly, which is located on the West Virginia side of the river. The entire series is exposed in Aurelius, Salem, Lawrence, and Ludlow townships. Sandstone is locally developed on the Sewickley horizon in the north central part, but at other places this member is represented by sandy shale. The other shale horizons are characterized by both the red and gray calcareous varieties.

In Morgan County the Monongahela series is exposed in parts of every township except York in the northwest corner. Both red and gray shales are prominently developed, but sandstone is present on the Fishpot and Uniontown horizons in the southern part of the county. From Morgan the belt of outcrops extends into the southeast corner of Muskingum County with exposures in Blue Rock, Meigs, Salt Creek, Rich Hill, and Union townships, but the entire thickness of the series is represented in Meigs Township only. Sandstone is locally present on the Upper Pittsburgh and Sewickley shale horizons and is very persistent on the Gilboy horizon. Where these sandstones disappear their place is taken by calcareous shale. Shales of similar kind also characterize the Uniontown, Arnoldsburg, and Fishpot members.

In Noble County the area of Monongahela exposures is divided into two parts by the valley of Duck Creek and its chief tributaries. West of this valley the series is exposed over much of Brookfield, Sharon, and Jackson townships and the southwestern parts of Noble and Olive townships. The eastern belt of exposures includes parts of every township in the eastern half of Noble County. Throughout these areas the clastic beds are represented chiefly by gray shale and sandstone. Sandstone is prominently developed on the Fishpot and Sewickley horizons in the east-central part of the county, but elsewhere these horizons are represented by gray calcareous shale. Thin lenses of sandstone occur at places on the Upper Pittsburgh, Arnoldsburg, and Uniontown horizons. Limestone is prominently developed on the Fishpot, Benwood, and Uniontown horizons in Sharon, Stock, Noble, and Marion townships, but where these beds become thin or disappear their places are taken by calcareous shale. Wilber Stout secured the following measurements in Section 26, Marion Township, which show in a representative fashion the character of the Monongahela series.

		Ft.	In.
Coal horizon, *Waynesburg*		..	..
Shale, soft, light		1	11
Shale, gray, sandy		7	8
Shale, pink, sandy		1	2
Coal horizon, *Little Waynesburg*		..	..
Shale, soft, gray		5	2
Shale, soft, and covered		6	0
Shale, sandstone, and covered		30	7
Coal blossom, *Uniontown*		1	0
Shale, gray and pink		5	2
Limestone, blue	*Uniontown*	..	5
Shale, calcareous, and marly limestone	*Uniontown*	1	10
Limestone, blue	*Uniontown*	..	6
Shale, light, calcareous	*Uniontown*	2	8
Shale, gray, and shaly sandstone, *Arnoldsburg*		7	10
Limestone, thick-bedded, with calcareous shale partings, *Arnoldsburg*		21	0
Shale, gray, sandy, *Fulton* horizon		6	0
Shale, calcareous, gray to pink in color		10	6
Limestone, thick-bedded, and calcareous shale, *Benwood*		61	10
Coal, poor, *Meigs Creek*		2	0
Shale, soft, calcareous		6	8
Shale, gray, sandy		11	0
Smut streak, *Fishpot* coal horizon		..	..
Shale, soft		2	8
Limestone, thick-bedded, with calcareous shale partings, *Fishpot*		22	4
Clay, calcareous, and covered		11	0
Shale		15	0
Covered interval		3	0
Coal horizon, *Pittsburgh*		..	..

The Monongahela series outcrops in every township in Monroe County, but in the eastern half the exposures occur only near the bottoms of the deep valleys. Thus the upper part of the series is a little above water level of the Ohio River along the eastern edge and along Sunfish Creek from northern Center Township to its mouth.. Similar narrow belts of outcrops are found along the Little Muskingum River and its tributaries in the southern part of this area. In the western half of the county the full thickness of the series is above drainage in the northwest corner. The character of the strata is similar to deposits of the same age in Noble County. Sandstone is developed on the Sewickley shale horizon over small areas in the southern part of the county. The Arnoldsburg member is represented by sandstone in the northeast corner and the Uniontown by sandstone in the northwest corner. Outside of the areas of sandstone development, the calcareous gray varieties predominate on all shale horizons. Limestone is extensively developed on the Redstone, Fishpot, Benwood, and Uniontown horizons. In Guernsey County exposures of the lower part of the series occur as isolated patches in Westland, Richland, Millwood, Wills, Oxford, and Londonderry townships. The beds require little consideration as the Redstone limestone is prominently developed and the Fishpot and Sewickley members are represented by much sandstone.

Belmont County contains a large area of Monongahela rocks for the top of the series is above drainage along all the major streams and the base of the series is exposed along Wheeling and McMahon Creeks in the northeastern quarter and along the headwaters of Stillwater Creek and its tributaries in the northwestern quarter.

The series in Belmont County consists chiefly of limestone and calcareous shale. The Redstone, Fishpot, Benwood, and Uniontown limestones are well exposed. Local deposits of sandstone are present on the Upper Pittsburgh horizon in the northwest corner, on the Fishpot shale horizon in the southeast quarter, and on the Arnoldsburg shale horizon in Richland Township. The Monongahela series in Harrison County is limited in its distribution to the high elevations in the eastern and southeastern parts. The areas where exposures occur include parts of Nottingham, Moorefield, Athens, Short Creek, Cadiz, Green, Rumley, and German townships, but the largest patches are found in Athens and Short Creek. Limestone and calcareous shale characterize the series in this county. Local deposits of sandstone are present on the Upper Pittsburgh horizon in the southeast corner, but the chief materials are lime-bearing shale. In Jefferson County the chief areas of Monongahela exposures are found south of Cross Creek which flows in an easterly direction from Unionport in western Wayne Township to Mingo Junction at the eastern edge of Steubenville Township. North of Cross Creek isolated patches are found capping the hills in Saline, Knox, Island Creek, Steubenville, Salem, Ross, and Springfield townships, but the total area is small. The Monongahela series in this county consists chiefly of limestone and gray calcareous and sandy shales. Sandstone is generally wanting, except in parts of Wells Township, where it is well developed on the Gilboy horizon. The following section secured near Tiltonville in Warren Township shows the general succession.

		Ft.	In.
Coal horizon, *Waynesburg*		..	..
Clay, bluish black		3	0
Shale, gray, and covered		18	0
Sandstone, shaly, *Gilboy*		10	0
Shale, with short covered intervals		14	8
Coal blossom, *Uniontown*		..	8
Clay, light, plastic		9	0
Shale, gray, and covered		35	0
Limestone, yellowish	*Arnoldsburg*	..	10
Shale and covered	*Arnoldsburg*	3	2
Limestone, yellowish	*Arnoldsburg*	1	0
Shale, green, *Fulton*		2	8
Shale and covered		2	10
Limestone, yellowish	*Benwood*	..	6
Shale and covered	*Benwood*	17	6
Limestone, yellowish	*Benwood*	..	10
Shale and covered	*Benwood*	27	2
Shale, black, with shaly coal	*Sewickley*	2	0
Shale, black, fissile	*Sewickley*	1	10
Sandstone, shaly, and shale		14	0
Shale, dark		14	0
Shale, bony, *Fishpot* coal horizon		..	6
Shale, with nodules of limestone, *Fishpot*		11	6
Covered interval		36	0
Coal horizon, *Pittsburgh, No. 8*		..	..

PERMIAN SYSTEM

The Permian system of rocks, which has generally been described in Ohio under the term Dunkard, outcrops over an area of about 1,830 square miles in the southeastern part of the State. This field of exposures extends from southern Jefferson County on the north to southern Meigs County on the south and includes parts of Meigs, Athens, Morgan, Washington, Noble, Monroe, Belmont, and Jefferson counties. The western boundary of the outcrops is represented roughly by a line drawn through Pomeroy, McConnelsville, Caldwell, Barnesville, St. Clairsville, and Dillonvale. East of this line Permian rocks cap all the higher elevations. The stratigraphic position of the Permian is immediately above and in contact with the top of the Monongahela series of the Pennsylvanian system. According to Stauffer and Schroyer, the thickness of the Permian in this State exceeds 600 feet. The character of the Permian rocks of Ohio is as follows:[1]

> "The Dunkard is a most variable series of rocks. There are sandstones, shales, beds of limestone, and coal; in fact it includes nearly all the different varieties of sediments from coarse sandstone and conglomerate to the finest grained shale. These change rather rapidly from one to the other, so that it is often impossible to trace a horizon for any great distance. And then too, there is considerable similarity between a number of beds at different stratigraphic

[1] Geol. Survey Ohio, 4th Ser., Bull. 22, p. 15, 1920.

elevations. This is especially true of the shales which are often featureless and devoid of any marks whereby they may be recognized. Shale is the most abundant rock in the series. The higher shales are often red in the northern part of the area, while to the south red is the prevailing color of the shale throughout the whole series. Selenite crystals are occasionally to be found in these red shales. This is especially true in the vicinity of Marietta. Most of the limestones occur in the northern part of the area where the sandstones are but poorly developed. As the limestones are traced southward they pass into calcareous shales which are often full of nuggets of lime. Finally these disappear as do also nearly all traces of coal beds, and the series becomes one of chiefly shale and sandstone. These latter increase materially in importance in the southern part of the Dunkard field."

The Permian rocks of Ohio are divided into the Washington series below and the Greene series above. Each series in turn is further separated into members. The following table shows the classification of the Permian beds and the average thickness of each member. The oldest appears at the bottom and the youngest at the top.

Generalized Section of the Permian System of Ohio [1]

Series		Member	General description	Thickness Ft.	In.
Greene		Gilmore	Sandstone and shale	52	0
		Gilmore	Limestone, local	2	0
		Nineveh	Sandstone, local, and shale	123	0
		Nineveh	Coal, shaly, local	1	0
		Nineveh	Limestone, irregular	8	0
			Shale and shaly sandstone	91	0
		Hostetter	Coal, thin, shaly, local	1	0
			Shale, variable	39	0
		Fish Creek	Coal, very local	1	0
		Fish Creek	Sandstone, local, and shale	44	0
		Dunkard	Coal, local, impure	1	0
		Jollytown	Sandstone, local, and shale	40	0
		Jollytown "A"	Coal, local, impure	2	0
Washington			Shale, variable	1	0
		Upper Washington	Limestone, irregular	5	0
		Hundred and Upper Marietta	Sandstone and shale	41	0
	Creston Red	Washington "A"	Coal, shaly, local	2	0
	Creston Red		Shale, local	8	0
	Creston Red	Middle Washington	Limestone	7	0
	Creston Red	Lower Washington	Shale, soft to hard	26	0
	Creston Red		Limestone	9	0
		Lower Marietta	Sandstone, local, and shale	10	0
		Washington	Coal, shaly	3	0
			Shale, soft to hard	15	0
		Little Washington	Coal, shaly	1	0
		Mannington	Sandstone, local, and shale	40	0
		Waynesburg "A"	Coal, unsteady	2	0
		Waynesburg	Sandstone and shale	44	0
		Elm Grove	Limestone	2	0
		Cassville	Shale, gray	5	0

[1] Generalized Section, Geol. Survey Ohio, 4th Ser., Bull. 34, 1929.

The shales of the Permian system have little potential value as sources of material for ceramic products. The shale is utilized at a few places, and the brick produced are sold to the local trade, but the quality is such that it can not compete in the open market with superior grades from other sources. On the outcrop the shales are variable in physical character and composition. In the southern part of the area they are generally red in color, but to the northeast they are a gray or buff shade. Iron compounds are present in comparatively large amounts and lime is present in both the finely disseminated form and as small nodular bodies embedded in the shale. Marietta and vicinity is the only place in Ohio where the Permian shales have been utilized to any extent for brick. Here the material is a red shale which stratigraphically belongs to the Creston Reds, which in turn are the southern equivalent of the members lying between the Lower and Upper Marietta sandstones. In the pit of the Marietta Shale Brick Company, located at the eastern edge of Section 36, Marietta Township, the exposures are as described below:

	Ft.	In.
Sandrock, greenish gray, micaceous	5	0
Shale, red and gray	2	0
Sandrock, greenish gray, micaceous	1	0
Shale, reddish brown	1	10
Shale, gray, sandy	1	0
Shale, reddish brown	3	9
Shale, soft, gray	2	0
Shale, soft, reddish brown	27	9
Shale, reddish brown, with thin layers of gray shale	4	0
Shale, soft, reddish brown	12	4
Sandrock, blue, micaceous, ferruginous	..	9
Shale, sandy, bluish gray, micaceous	4	2
Shale, reddish brown	8	9
Bottom of pit	..	..

A sample of shale was cut from the exposures in this pit on June 29, 1929, and was submitted for chemical analysis and other tests. The results are given below:

Sample No. 49

Tests of Creston Red shale from pit of Marietta Shale Brick Company, Marietta, Washington County

Chemical analysis	
Water, hydroscopic, H_2O-	1.73
Water, combined, H_2O+	...
Silica, SiO_2	55.80
Alumina, Al_2O_3	18.65
Titanic oxide, TiO_2	1.45
Phosphorus pentoxide, P_2O_5	0.19
Ferric oxide, Fe_2O_3	8.16
Ferrous oxide, FeO	...
Lime, CaO	2.08
Magnesia, MgO	1.95
Sodium oxide, Na_2O	0.93

Analysis by U. S. Bureau of Mines

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .178 \\ Na_2O & .050 \\ CaO & .112 \\ MgO & .104 \\ FeO & .394 \\ MnO & \ldots \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 2.992 \\ TiO_2 & 0.077 \\ P_2O_5 & 0.010 \end{array}\right.$$

RO .838

Potassium oxide, K_2O..... 3.33
Manganese oxide, MnO.... trace
Sulphur trioxide, SO_3...... ...

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material has good plasticity. A good column is extruded from the die.

Time of slaking: 23.78 minutes.

Water of plasticity: 19.03 per cent.

Dry shrinkage:

Volume: 16.51 per cent.

Linear: 5.23 per cent.

Drying behavior: Extreme care is necessary in drying to avoid cracking.

Dry modulus of rupture: 573 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	14.30	13.72	4.4	6.50	2.20	2.57
04	6.59	17.55	5.5	2.83	2.32	2.49
02	6.04	19.15	6.0	2.56	2.36	2.52
1	5.00	20.17	6.3	2.10	2.38	2.51
3	3.47	20.60	6.4	1.45	2.39	2.48
5	9.29	17.82	5.6	0.39	2.32	2.35
7	8.89	7.43	2.4	4.27	2.07	2.28

Fired modulus of rupture:

Cone 02, 4,626 pounds per square inch.

Cone 3, 5,437 pounds per square inch.

Fired specific impact strength:

Cone 03, 1.64 centimeter kilograms per square centimeter.

Cone 3, 1.19 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 3, 14,853 pounds per square inch

Best firing range: Cone 08 to cone 3.

Overfiring temperature: Cone 5.

Pyrometric cone equivalent: Cone 9.

Scumming: Scum occurs on trials fired to cone 01 and lower but no scum is apparent on trials fired above cone 01. One pound of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: A good salt glaze is produced at both 2,100°F. and 2,050°F. The color at both temperatures is a yellow and reddish brown mottle on a very dark yellowish green background. A glaze is not produced at 2,100°F. on material to which $BaCO_3$ has been added.

Utilization: This material was being utilized for the production of face brick. Other possibilities for utilization are common brick, drain tile, and hollow tile. The fired material develops a good red color at cone 04.

Shale from approximately the same horizon has been used for a number of years by the Acme Brick Company of Marietta located in Section 23, Marietta Township. To the writer's knowledge shales of Permian age are not utilized for ceramic purposes at any place in Ohio outside of the Marietta district.

CHAPTER III

SURFACE CLAYS

By R. E. Lamborn, Chester R. Austin, Downs Schaaf

The surficial deposits include the unconsolidated materials of variable texture, chemical composition, and thickness which mantle the upper surface of bedrock. Such deposits have a wide distribution as they are present at all places on the land surface except where the rock surface is too steep or too exposed to the elements of weather to permit of their accumulation.

CLASSIFICATION

The surficial deposits have been formed by the action on bedrock of the various weathering and erosive agents. On the basis of their origin and mode of accumulation several classes of such materials are recognized.

Residual Deposits

Residual deposits have been formed by the breaking up of bedrock in place by mechanical and chemical processes induced by the weather. Transportation of the products of weathering is not involved. Through daily temperature changes and the expansive force of freezing moisture in the rock pores, the material is mechanically disrupted until a residual mantle is formed of sufficient depth to protect the underlying bedrock from the further effects of such mechanical agents. Chemical changes brought about by the oxygen, carbon dioxide, and moisture may also take place, but where the common varieties of sedimentary rock are involved, such as sandstone, conglomerate, and shale, the effects of these agents are small. The residual products of weathering are generally mantles of variable texture having a siliceous composition with generally small but varying amounts of iron oxides and calcium carbonate.

Residual deposits in Ohio are limited in their distribution to the high elevations in the southeastern part of the State outside of the area subjected to continental glaciation. Even here the rough topography permits rapid removal of the products of weathering by rain wash. Residual deposits are not utilized in Ohio as sources of material for brick and tile.

Eolian Deposits

This class includes those deposits formed by material which has been transported and deposited by the wind. Surface deposits of this type are of slight importance except in regions where there has been little vegetation and scanty rainfall. The material deposited by the wind consists of

MAP OF OHIO
SHOWING LOCATION OF
SAMPLES OF SHALES
AND SURFACE CLAYS
1936

sands, silts, and clays of varying composition. In Ohio wind-blown mantle deposits are of doubtful occurrence although fine sands and silts distributed irregularly at intermediate and high elevations in the vicinity of Cincinnati and Zanesville have been assigned to this class. The material has been used extensively for molding sand and to a very limited extent for ceramic purposes.

Alluvial Deposits

Materials deposited by running water are known as alluvial deposits. Deposits of this type are generally laid down where running waters loaded with sediment in suspension suffer a decrease in velocity. These materials show a textural range from boulders, cobbles, and gravels to the finest silts and clays. The chemical composition is likewise variable as the accumulated materials come from many sources. In their areal distribution in Ohio the alluvial deposits of value to the ceramic industry are confined to old valleys. These silts and clays have been utilized to a small extent for the production of brick and tile.

Glacial Deposits

Of the various types of surficial deposits in Ohio those of glacial origin are by far the most important as they are distributed over approximately three-fourths of the State and as certain types of these deposits are used extensively for the production of brick and tile.

Deposits of glacial origin were laid down during the period of continental glaciation or Pleistocene Period, the last preceding the Recent Period, the one in which we live. During this period several ice invasions crossed the borders of Ohio from southern Canada and covered the northern and western parts of the State with a thick accumulation of ice. The southern limit of glacial ice extension may be represented roughly by a line extending from St. Clair, Columbiana County, westward near Minerva to Canton, Stark County. At the latter place the line bears southwest near Millersburg to the western edge of Holmes County, where it turns to the south and with a few broad bends passes through western Coshocton, eastern Licking, and western Muskingum County to the vicinity of New Lexington, Perry County. Here the direction is again to the southwest for the boundary line passes through southeastern Fairfield, northwestern Hocking, southern Ross, northwestern Pike, southeastern Highland, northwestern Adams, and southeastern Brown counties, crossing the Ohio River Valley near the town of Ripley. That part of Ohio lying to the northwest of this line has been covered by glacial ice.

During the period of continental glaciation great quantities of rock debris were eroded from the land surface over which the ice passed, transported by ice movement, and deposited with the melting of the ice. The material thus deposited, known as glacial drift , occurs as a surficial mantle and consists of boulders, gravel, sand, silt, and clay without stratification or definite arrangement if deposited directly by the ice or in the stratified form if laid down by waters liberated by ice melting. Glacial drift so deposited occurs in various types of deposits called moraines. The fine-grained silts and clays are utilized for ceramic purposes.

Terminal moraines. These moraines were formed around the borders of the ice either at the time of its maximum extent or during periods of temporary halt in the ice front during recession, and are comparatively rough or hilly tracts having their elongation in general at right angles to the direction of ice movement. The material of such moraines consists in large part of unstratified drift or till, although stratified sands and gravels are generally present and add to the topographic expression of the deposit.

In the glaciated region of Ohio the terminal moraines are generally crescent shaped in horizontal outline with their greatest extension in an east-west direction. With the retreat of the ice from the Scioto and Miami drainage basins no less than ten of these moraines were formed. The width varies from a fraction of a mile to as much as ten miles or more. In places the deposits are dotted by sand and gravel knolls which rise above the general level of the surrounding country but at other places the topographic expression of the deposits is slight.

Ground moraines. The glacial deposits which have been laid down beneath the glacial ice or at the end of the ice during uniform recession are ground moraines. The material is a till or boulder clay although lenses of stratified sand and gravel are of frequent occurrence. In contrast to terminal moraines, the topography of ground moraines is comparatively flat and monotonous. In Ohio ground moraines are wide spread in extent as they are of universal occurrence between the recessional terminal deposits.

Glacio-lacustrine deposits. These materials include those deposits laid down in temporary lakes formed around the margin of the ice during the recession of the ice sheet. Such materials are glacial in mode of origin but the deposits show the characteristics of assortment, gradation, and stratification produced by subsidence in quiet waters. Temporary glacial lakes occurred over a large area in Ohio bordering Lake Erie on the south and southwest.

Glacio-fluvial deposits. Material of glacial origin which has been transported by streams formed by melting of the ice and which has been deposited in or along the channels makes up these deposits. Valleys of many large southern-flowing streams in Ohio contain much material having this origin.

The surficial deposits of the various types, either residual, alluvial, eolian, or glacial, are widely distributed in Ohio. The thickness of the deposits ranges from 0 to 600 feet. The thinnest portions in general are found in the residual mantles of the southeastern part of the State and the thickest parts in the deep preglacial and interglacial valleys that have been filled with glacial drift. The chemical composition and texture are likewise subject to change as the mode of accumulation and source of the material of the deposits vary. The greatest variations are probably realized in the glacial drift which is wide spread in its distribution. The presence of glacial drift has influenced to some extent the character of the transported surficial deposits beyond the limits of ice invasion.

TESTS OF SURFACE CLAYS

The surface materials utilized for ceramic purposes are in large part of glacial and alluvial origin. Deposits of both types are variable in character from place to place and the value of such deposits for ceramic purposes can not be predicted on the basis of areal distribution. The glacial deposits which are utilized are generally dense, tough, gritty materials consisting chiefly of silt and clay with some glacial pebbles scattered through the mass. The percentage of pebbles generally increases from the surface downward and this percentage often limits the depth to which the material can be utilized. Glacial materials suitable for ceramic purposes are found chiefly in ground moraines and in beds of abandoned lakes of glacial origin. The alluvial materials possessing qualities suitable for ceramic use are distributed along flood plains of large and medium-sized valleys. The eolian deposits of ceramic value are limited in extent and are of slight value. Surface deposits are utilized chiefly in the western half of Ohio where the bedrock is either limestone or calcareous shale and therefore not adapted to ceramic uses. The local demand for drain tile in the northern and northwestern parts of the State is supplied by many small plants utilizing such surface materials.

The tests of samples collected at various localities are given by counties. Eleven samples of surface clay were collected by R. E. Lamborn of the Geological Survey during the summer of 1929. By permission of the National Bureau of Standards tests of fifteen samples of surface clay, secured by A. E. MacGee in 1926-1927, are also included.

Allen County. Glacial drift was formerly utilized for the production of brick at the plant of the Lima Brick Company located near Lima in Section 19, Bath Township. The material is a dark-colored drift containing silt, clay, and many pebbles of shale, limestone, and other materials, and having a maximum thickness of about 30 feet. The brick were dried in open air racks and burned in scove kilns. The plant, however, has now been abandoned. A sample of the upper 10 feet of the material now exposed in the pit was secured by A. E. MacGee of the National Bureau of Standards.

Sample No. 210

Tests of glacial clay from the pit of the Lima Brick Company, Lima, Allen County (Tests by the Bureau of Standards)[1]

Chemical analysis

Loss on ignition	9.3
Silica, SiO_2	53.7
Alumina, Al_2O_3	13.3
Ferric oxide, Fe_2O_3	5.6
Lime, CaO	8.1
Magnesia, MgO	2.7
Titanic oxide, TiO_2	0.7
Sodium oxide, Na_2O	1.0
Potassium oxide, K_2O	2.5
Sulphur, S	0.2
Total carbon, C	2.5

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .19 \\ Na_2O & .07 \\ CaO & .61 \\ MgO & .20 \\ FeO & .38 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 4.04 \\ TiO_2 & 0.05 \end{array}\right.$$

$$RO \quad 1.45$$

Physical tests

Tempering water:	About 22 per cent.
Drying linear shrinkage:	About 4 to 5 per cent.
Drying volume shrinkage:	About 14 to 15 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	0.0	0.0	18.3	Pink
Cone 06½	1.5	4.3	19.6	Pink
Cone 04	1.8	5.4	14.0	Light brown
Cone 03	2.1	6.2	16.2	Gray
Cone 02	8.5	23.5	4.8	Gray, white lime spots
Cone 01	10.4	28.1	3.8	Grayish brown speckled white
Cone 1	7.4	20.7	3.3	Gray brown

Overburning temperature: About cone 2 (1,135°C. or 2,075°F.).

Best apparent burning range: Cone 04 to cone 01 (1,050°C. to 1,110°C. or 1,922°F. to 2,030°F.).

Total linear shrinkage at cone 01: About 15 per cent.

Deformation temperature: Cone 3 (1,145°C. or 2,093°F.).

Darke County. The B. F. Clark Tile Plant is located at Versailles in the southern part of Section 19, Wayne Township. The machinery is electrically operated and the plant has a capacity of about 7,000 tile a day. The material utilized is glacial drift having a thickness ranging from 2 feet 6 inches to 13 feet; it is somewhat calcareous but relatively free from limestone pebbles. Pebbles, however, increase in number downward and their presence in large numbers limits the depth to which the material can be worked. A description of the exposures follows:

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

	Ft.	In.
Soil	..	8
Silt and clay, dark, bluish gray	2	0
Silt and clay, dark yellow gray, with pebbles of limestone. Material not used	..	..

A sample of the materials utilized at this place, having a total thickness of 2 feet 8 inches, was collected on June 6, 1929, for chemical analysis and other tests. The results are given below.

Sample No. 4

Tests of glacial clay from the pit of the B. F. Clark Tile Plant, Versailles, Darke County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.95
Water, combined, H_2O+	4.25
Silica, SiO_2	64.44
Alumina, Al_2O_3	15.56
Titanic oxide, TiO_2	1.02
Phosphorus pentoxide, P_2O_5	0.12
Ferric oxide, Fe_2O_3	4.79
Ferrous oxide, FeO	0.84
Lime, CaO	1.43
Magnesia, MgO	1.78
Sodium oxide, Na_2O	0.27
Potassium oxide, K_2O	2.32
Manganese oxide, MnO	0.07
Sulphur trioxide, SO_3	0.08
Carbon dioxide, CO_2	0.22
Carbon, organic, C	0.95

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .149 \\ Na_2O & .018 \\ CaO & .092 \\ MgO & .114 \\ FeO & .331 \\ MnO & .004 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 4.141 \\ TiO_2 & 0.065 \\ P_2O_5 & 0.008 \end{array}\right.$$

$$RO \quad .708$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: The material is very plastic. A good column is extruded from the die.

Time of slaking: 24 hours.

Water of plasticity: 28.63 per cent.

Drying shrinkage:

Volume: 27.61 per cent.

Linear: 8.46 per cent.

Drying behavior: Extreme care is necessary in drying this material to avoid cracking.

Dry modulus of rupture: 932 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
012	30.32	0.55	0.18	17.10	1.79	2.59
010	29.20	3.31	1.1	16.00	1.82	2.58
08	27.20	5.74	1.9	14.50	1.87	2.56
06	20.64	13.22	4.2	10.18	2.03	2.09
04	8.28	18.74	5.9	3.80	2.19	3.38
02	6.41	20.03	6.3	2.89	2.22	2.37
01	5.47	20.68	6.5	2.44	2.24	2.37

Fired modulus of rupture:

Cone 06, 1,429 pounds per square inch.

Cone 09, 2,020 pounds per square inch.

Fired specific impact strength:

Cone 09, 1.08 centimeter kilograms per square centimeter.

Cone 06, 1.37 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 01, 18,255 pounds per square inch.

Best firing range: Cone 012 to cone 04.

Overfiring temperature: Cone 01.

Pyrometric cone equivalent: Cone 2. Cones bloated.

Scumming: A slight scum occurs on trials fired at cone 012 and cone 06 but no scum is apparent on trials fired at cone 010 and at cone 08. Scum is not apparent on trials fired above cone 06. One pound of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: This material does not withstand the temperature necessary for the development of a good salt glaze.

Utilization: This material was being used for the production of drain tile. It can be used also for simple hollow tile shapes if care is exercised in drying and if sand is added to the mix. On firing the material develops a good red color at cone 04.

Delaware County. Glacial drift is used extensively by the Delaware Clay Company of Delaware for the manufacture of fireproofing. This plant was built in 1901 and has a capacity of about 50,000 pieces a day. A description of the drift exposures follows:

	Ft.	In.
Drift, yellowish, silty, free from pebbles	3	0
Drift, yellowish brown with some pebbles of limestone and foreign rock	4	6
Bottom of pit	..	..

At greater depths the drift contains so much limestone and foreign material that it can not be used successfully. A sample was cut on June 7, 1929, at the place where the above measurements were secured and was submitted for testing.

Sample No. 5

*Tests of glacial clays from the pit of the Delaware Clay Co.,
Delaware, Delaware County*

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.86
Water, combined, H_2O+..	3.40
Silica, SiO_2	60.91
Alumina, Al_2O_3	12.38
Titanic oxide, TiO_2	0.70
Phosphorus pentoxide, P_2O_5	0.15
Ferric oxide, Fe_2O_3	5.29
Ferrous oxide, FeO	1.35
Lime, CaO	3.70
Magnesia, MgO	2.68
Sodium oxide, Na_2O	0.46
Potassium oxide, K_2O	2.40
Manganese oxide, MnO	0.06
Sulphur, S	0.02
Carbon dioxide, CO_2	4.20
Carbon, organic, C	0.55

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .194 \\ Na_2O & .037 \\ CaO & .299 \\ MgO & .216 \\ FeO & .493 \\ MnO & .005 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 4.920 \\ TiO_2 & 0.056 \\ P_2O_5 & 0.012 \end{array}\right.$$

$$RO \quad 1.244$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material is very plastic and sticky. A very good column is extruded from the die.

Time of slaking: 79.33 minutes.

Water of plasticity: 21.67 per cent.

Drying shrinkage:

Volume: 17.47 per cent.

Linear: 5.52 per cent.

Drying behavior: Extreme care is necessary in drying this material to avoid cracking.

Dry modulus of rupture: 475 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
012	31.81	0.41+	0.13+	17.80	1.79	2.61
010	31.50	0.26	0.08	17.30	1.80	2.60
08	31.75	1.52	0.5	17.40	1.82	2.66
06	29.79	4.33	1.4	15.93	1.86	2.66
04	24.80	7.51	2.4	12.77	1.95	2.58
02	19.62	13.04	4.2	9.58	2.08	2.57
01	17.03	15.80	5.0	7.98	2.14	2.57

Fired modulus of rupture:

Cone 06, 1,664 pounds per square inch.

Cone 02, 1,822 pounds per square inch.

Fired specific impact strength:

Cone 06, 1.32 centimeter kilograms per square centimeter.

Cone 03, 1.39 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 04, 4,356 pounds per square inch.

Best firing range: Cone 08 to cone 01.

Overfiring temperature: Cone 2.

Pyrometric cone equivalent: Cone 5.

Scumming: Scum occurs on all trials fired above cone 012. Scum is not apparent on trials fired at cone 012 or at lower temperatures. Three pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: This material does not withstand the temperature necessary for the development of a good salt glaze.

Utilization: This material was being used for the production of drain tile and hollow tile. On firing the material develops a good red color at cone 04.

Fayette County. The only plant producing ceramic products from glacial drift in Fayette County is owned and operated by A. W. Rife at Good Hope, Wayne Township. This plant had been operating for over 25 years. Drain tile, which is the sole product, is made in sizes ranging from 4 to 12 inches in diameter. The capacity of the plant is about 6,500 4-inch tile per day. The surface material used has a thickness of about 3 feet 6 inches. A description is given below:

	Ft.	In.
Silt and clay, black, carbonaceous	2	6
Silt and clay, gray, plastic, with a few small pebbles	1	0
Bottom of pit	..	..

Pebbles of limestone increase in number with the depth and their presence limits the thickness which can be utilized. A sample collected on June 10, 1929, was submitted for testing with the following results:

Sample No. 9

Tests of glacial clay from the pit at the plant of A. W. Rife, Good Hope, Fayette County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	2.15
Water, combined, H_2O+	4.30
Silica, SiO_2	68.07
Alumina, Al_2O_3	11.55
Titanic oxide, TiO_2	0.68
Phosphorus pentoxide, P_2O_5	0.15
Ferric oxide, Fe_2O_3	4.71
Ferrous oxide, FeO	1.17
Lime, CaO	1.20
Magnesia, MgO	1.51
Sodium oxide, Na_2O	0.82
Potassium oxide, K_2O	2.27
Manganese oxide, MnO	0.11
Sulphur, S	trace
Carbon dioxide, CO_2	0.44
Carbon, organic, C	1.07

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .197 \\ Na_2O & .071 \\ CaO & .104 \\ MgO & .131 \\ FeO & .468 \\ MnO & .009 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 5.893 \\ TiO_2 & 0.059 \\ P_2O_5 & 0.013 \end{array}\right.$$

RO	.980

Physical properties, determined by Chester R. Austin
Properties in green state

Workability: The material is very plastic and sticky. A very good column is extruded from the die.

Time of slaking: Over 24 hours.

Water of plasticity: 25.92 per cent.

Drying shrinkage:

Volume: 27.61 per cent.

Linear: 8.46 per cent.

Burning behavior: Extreme care is necessary in drying this material to prevent cracking.

Dry modulus of rupture: 412 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
012	26.90	1.40+	0.5+	14.70	1.83	2.51
010	27.78	0.14	0.04	14.90	1.85	2.57
08	26.55	1.31	0.4	14.20	1.87	2.55
06	26.26	3.58	1.2	13.72	1.92	2.60

Fired modulus of rupture:

Cone 08, 872 pounds per square inch.

Cone 05, 1,923 pounds per square inch.

Fired specific impact strength:

Cone 08, 1.09 centimeter kilograms per square centimeter.

Cone 05, 1.11 centimeter kilograms per square centimeter.

Fired crushing strength:

Cone 05, 4,877 pounds per square inch.

Best firing range: Cone 010 to cone 05.

Overfiring temperature: Cone 05.

Pyrometric cone equivalent: Cone 4-5. Cones bloated.

Scumming: Scum occurs throughout the entire firing range of this material. Two pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: This material does not withstand the temperature necessary for the development of a good salt glaze.

Utilization: This material was being used for the manufacture of drain tile. On firing the material develops a good red color at cone 05.

Franklin County. Drain tile and hollow building tile are produced from alluvial silts and clays at the plant of F. H. Everal located along the valley of Alum Creek in Blendon Township near Westerville. The material utilized is a fine-grained, even-textured alluvial silt with an average thickness of about 4 feet. At greater depths it becomes too sandy to yield good results. A sample from this pit was secured by A. E. MacGee of the National Bureau of Standards.

Sample No. 211

Tests of alluvial clays from the pit of Frank H. Everal Company, Westerville, Franklin County. (Tests by the Bureau of Standards)[1]

Chemical analysis

Loss on ignition	6.5
Silica, SiO_2	67.7
Alumina, Al_2O_3	14.6
Ferric oxide, Fe_2O_3	5.2
Lime, CaO	0.9
Magnesia, MgO	1.2
Titanic oxide, TiO_2	1.0
Total alkali chlorides computed as Na_2O	2.1
Sulphur, S	0.1
Total carbon, C	0.7

Oxide ratio

$$\left.\begin{array}{ll} \text{Alkalies, } Na_2O \text{ basis} & .14 \\ CaO & .06 \\ MgO & .08 \\ FeO & .32 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 4.63 \\ TiO_2 & 0.07 \end{array}\right.$$

$$RO \quad .60$$

Physical tests

Tempering water:	About 28 per cent
Drying linear shrinkage:	About 7 to 8 per cent
Drying volume shrinkage	About 24 per cent

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	1.0	2.9	17.8	Orange
Cone 06	2.1	6.3	16.3	Brick red
Cone 04	5.5	15.6	9.1	Salmon
Cone 03	8.2	22.6	5.6	Rich red
Cone 6	9.3	25.3	0.9	Dark red
Cone 7	8.1	22.3	1.2	Dark red

Overburning temperature: About cone 7 to cone 8 (1,210°C. to 1,225°C. or 2,210°F. to 2,237°F.).

Best apparent burning range: Cone 04 to cone 4 (1,050°C. to 1,165°C. or 1,922°F. to 2,129°F.).

Total linear shrinkage at cone 6: About 16 to 17 per cent.

Deformation temperature: Cone 10 (1,260°C. or 2,300°F.).

Gallia County. Silts and clays from the Ohio River Valley form the basis of operations for a small plant located at Gallipolis. The plant is known as the Gallipolis Tile and Brick Works and its products are drain tile and common brick. A sample of silt was secured for testing by A. E. MacGee of the National Bureau of Standards.

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

Sample No. 212

Tests of alluvial clay from the pit of the Gallipolis Brick & Tile Co., Gallipolis, Gallia County. (Tests by the Bureau of Standards)[1]

Chemical analysis

Loss on ignition	7.9
Silica, SiO_2	63.3
Alumina, Al_2O_3	18.3
Ferric oxide, Fe_2O_3	5.2
Lime, CaO	0.3
Magnesia, MgO	1.5
Titanic oxide, TiO_2	1.1
Total alkali chlorides computed as Na_2O	2.1
Sulphur, S	0.1
Total carbon, C	0.3

Oxide ratio

Alkalies, Na_2O basis	.11	Al_2O_3	1.00	SiO_2	3.46
CaO	.02			TiO_2	0.06
MgO	.08				
FeO	.25				
RO	.46				

Physical tests

Tempering water	About 27 per cent
Drying linear shrinkage	About 7 per cent
Drying volume shrinkage	About 22 to 23 per cent

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	1.0	3.1	18.5	Salmon
Cone 06	3.1	8.9	16.4	Salmon
Cone 04	7.4	20.6	8.1	Tan
Cone 3½	8.9	24.5	3.4	Dark red
Cone 6	8.3	22.9	2.8	Dark red
Cone 7	8.4	23.1	2.1	Dark red

Overburning temperature: About cone 8 (1,225°C. or 2,237°F.).

Best apparent burning range: Cone 04 to cone 6 (1,050°C. to 1,190°C. or 1,922°F. to 2,174° F.).

Total linear shrinkage at cone 3½: About 16 per cent.

Deformation temperature: Cone 13 (1,350°C. or 2,462°F.).

Hamilton County. Common brick are produced from glacial drift at the plant of the Mount Healthy Brick Company at Mount Healthy in the southwest corner of Springfield Township. The material utilized is a mixture of glacial silt and clay of a reddish color which has been dug to a depth of about 4½ feet. Pebbles of limestone are common in the lower part of the bed. The material is worked by steam shovel and burned in scove kilns. A sample was collected by A. E. MacGee of the National Bureau of Standards.

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

Sample No. 213

Tests of glacial clay from the pit of the Mount Healthy Brick Company, Mount Healthy, Hamilton County. (Tests by the Bureau of Standards.)[1]

Chemical analysis

Loss on ignition	5.8
Silica, SiO_2	73.9
Alumina, Al_2O_3	11.5
Ferric oxide, Fe_2O_3	4.2
Lime, CaO	0.3
Magnesia, MgO	0.7
Titanic oxide, TiO_2	0.9
Sodium oxide, Na_2O	0.6
Potassium oxide, K_2O	1.5
Sulphur, S	0.1
Total carbon, C	0.5

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .13 \\ Na_2O & .05 \\ CaO & .02 \\ MgO & .06 \\ FeO & .33 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 6.42 \\ TiO_2 & 0.08 \end{array}\right.$$

RO .59

Physical tests

Tempering water: About 30 per cent.
Drying linear shrinkage: About 8 per cent.
Drying volume shrinkage: About 26 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	0.0	0.0	20	Brick red
Cone 06	0.4	1.1	20	Brick red
Cone 04	2.2	6.5	14	Tan
Cone 4	7.9	21.9	8.7	Red
Cone 6	7.2	20.1	7.6	Dark red
Cone 7	8.0	22.0	5.4	Dark red
Cone 8	8.8	24.1	2.8	Maroon
Cone 8½	6.8	19	1.6	Maroon
Cone 9	5.7	16.2	0.1	Brown

Overburning temperature: Cone 8 to cone 9 (1,225°C. to 1,250°C. or 2,237°F. to 2,282°F.).

Best apparent burning range: Cone 04 to cone 6 (1,050°C. to 1,190°C. or 1,922°F. to 2,174°F.).

Total linear shrinkage at cone 8: About 16 to 17 per cent.

Deformation temperature: Cone 12 (1,310°C. or 2,390°F.).

Common brick and building tile are produced by the Mitchell Brick Company at Saylor Park and find a ready sale in Cincinnati and adjoining suburbs. The materials utilized are alluvial silts and clays from the Ohio River Valley. A description of the exposures is given below:

	Ft.	In.
Soil	—	6
Silts and clays, yellowish brown	10	0
Silt, clay, and fine sand	1	6
Bottom of pit.		

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

The depth to which the material can be utilized is determined by the amount of sand, as this element increases in amount and coarseness downward. Both brick and building tile are produced. The stiff mud process is used and the material is burned in open arches. A sample of the exposures in the pit having a total thickness of about 12 feet was taken on June 12, 1929, and was submitted for testing with the following results:

Sample No. 1

Tests of alluvial clays from the pit of the Mitchell Brick Company, Saylor Park Station, Cincinnati, Hamilton County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.55
Water, combined, H_2O+	3.77
Silica, SiO_2	71.56
Alumina, Al_2O_3	12.21
Titanic oxide, TiO_2	0.86
Phosphorus pentoxide, P_2O_5	0.14
Ferric oxide, Fe_2O_3	3.88
Ferrous oxide, FeO	1.35
Lime, CaO	0.55
Magnesia, MgO	1.21
Sodium oxide, Na_2O	0.68
Potassium oxide, K_2O	1.82
Manganese oxide, MnO	0.09
Sulphur, S	0.02
Carbon dioxide, CO_2	0.28
Carbon, organic, C	0.25

Oxide ratio

$$\left.\begin{array}{ll} K_2O & 1.49 \\ Na_2O & .056 \\ CaO & .045 \\ MgO & .099 \\ FeO & .396 \\ MnO & .007 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 5.861 \\ TiO_2 & 0.070 \\ P_2O_5 & 0.011 \end{array}\right.$$

RO .752

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material is very plastic. A very good column is extruded from the die.

Time of slaking: 58.51 minutes.

Water of plasticity: 22.07 per cent.

Drying shrinkage:

Volume: 13.30 per cent.

Linear: 4.25 per cent.

Drying behavior: Extreme care is necessary in drying this material to avoid cracking.

Dry modulus of rupture: 341 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	29.99	3.98	1.3	16.17	1.86	2.65
04	26.11	9.35	3.0	13.43	1.94	2.62
02	25.62	10.68	3.5	13.02	1.97	2.65
1	26.14	12.87	4.1	12.96	2.02	2.73
3	23.58	15.20	4.8	11.39	2.08	2.73
5	16.94	16.80	5.3	7.97	2.12	2.56
7	13.95	17.79	5.6	6.47	2.16	2.51

Fired modulus of rupture:
Cone 1, 1,934 pounds per square inch.
Cone 7, 2,847 pounds per square inch.
Fired specific impact strength:
Cone 2, 1.18 centimeter kilograms per square centimeter.
Cone 7, 1.23 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 7, 14,263 pounds per square inch.
Best firing range: Cone 06 to cone 7.
Overfiring temperature: Cone 9.
Pyrometric cone equivalent: Cone 10-11.

Scumming: Scum occurs on trials fired to cone 01 and lower but no scum is apparent on trials fired to cone 2 and higher. Two pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: A very good smooth glaze, having a pinkish gray color with some yellowish green stains, is produced at 2,100°F. A good glaze is also produced at 2,050°F., having a dark gray color with fine red dots intermingling. When $BaCO_3$ is added the glaze produced at 2,100°F. has very good chocolate brown color.

Utilization: This material was being utilized for the production of common brick. It can be used also for face brick and simple hollow tile shapes. On firing the material develops a good red color at cone 04.

Hancock County. Glacial drift is the source for the raw material used at the plant of the Hancock Brick and Tile Company at Findlay in Section 30, Marion Township. The material utilized is a somewhat plastic glacial drift containing a few pebbles and having an average thickness of about 4½ feet. The percentage of sand in the drift tends to increase downward and its occurrence in harmful proportions practically limits the depth to which the material can be utilized. The plant is modern throughout and tile of a good quality are produced. A sample of the material was collected by A. E. MacGee of the National Bureau of Standards.

Sample No. 214

Tests of glacial clay from the pit of the Hancock Brick and Tile Company, Findlay, Hancock County. (Tests by the Bureau of Standards.)[1]

Chemical analysis		Oxide ratio					
Loss on ignition	6.2	K_2O	.20				
Silica, SiO_2	67.6	Na_2O	.07			SiO_2	5.28
Alumina, Al_2O_3	12.8	CaO	.09	Al_2O_3	1.00		
Ferric oxide, Fe_2O_3	5.6	MgO	.11			TiO_2	0.06
Lime, CaO	1.2	FeO	.39				
Magnesia, MgO	1.4		—				
Titanic oxide, TiO_2	0.8	RO	.86				
Sodium oxide, Na_2O	0.9						
Potassium oxide, K_2O	2.5						
Sulphur, S	0.0						
Total carbon, C	1.1						

Physical tests

Tempering water: About 27 per cent.
Drying linear shrinkage: About 7 to 8 per cent.
Drying volume shrinkage: About 23 to 24 per cent.

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	0.8	2.3	15.6	Buff
Cone 06	1.3	3.9	14.8	Salmon
Cone 04	4.2	12.2	9.7	Tan
Cone 03	6.2	17.6	6.9	Red
Cone 01	7.1	19.7	4.1	Dark red
Cone 1	7.8	21.6	1.9	Dark red
Cone 5	6.2	17.4	1.1	Dark red

Overburning temperature: About cone 2 (1,135°C. or 2,075°F.).

Best apparent burning range: Cone 04 to cone 02 (1,050°C. to 1,110°C. or 1,922°F. to 2,030°F.).

Total linear shrinkage at cone 1: About 15 per cent.

Deformation temperature: Cone 8 (1,225°C. or 2,237°F.).

Henry County. One of the largest ceramic plants in Henry County is the Napoleon Brick & Tile Works at Napoleon. This plant has been operating on glacial silt and clay since 1898 from which it has manufactured both brick and drain tile. Since 1928 tile has been the sole product. A description of the material utilized is given in the following section:

	Ft.	In.
Soil	..	8
Silt and clay, dark	2	4
Silt and clay with nodules and pebbles of limestone, forms bottom of pit	..	..

Both the soil and the 2-foot 4-inch layer of silt are utilized. This material was sampled on June 4, 1929, by boring two holes with a soil auger to the required depth and collecting the material removed from these holes. This sample submitted for testing shows the following characteristics:

Sample No. 8

Tests of glacial clay from the pit of the Napoleon Brick and Tile Works, Napoleon, Henry County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.50
Water, combined, H_2O+	4.21
Silica, SiO_2	64.22
Alumina, Al_2O_3	15.44
Titanic oxide, TiO_2	0.70
Phosphorus pentoxide, P_2O_5	0.12
Ferric oxide, Fe_2O_3	4.25
Ferrous oxide, FeO	1.22
Lime, CaO	1.60

Oxide ratio

K_2O	.175	Al_2O_3	1.00	SiO_2	4.159
Na_2O	.071			TiO_2	0.045
CaO	.104			P_2O_5	0.008
MgO	.112				
FeO	.327				
MnO	.003				
RO	.792				

Magnesia, MgO	1.73
Sodium oxide, Na_2O	1.10
Potassium oxide, K_2O	2.71
Manganese oxide, MnO....	0.05
Sulphur trioxide, SO_3	0.07
Carbon dioxide, CO_2	0.35
Carbon, organic, C........	0.98

Physical properties, determined by Chester R. Austin
Properties in green state

Workability: This material is very plastic and sticky. A very good column is extruded from the die.

Time of slaking: Over 24 hours.

Water of plasticity: 26.89 per cent.

Drying shrinkage:

Volume: 25.39 per cent.

Linear: 7.83 per cent.

Drying behavior: Extreme care is necessary in drying this material to avoid cracking.

Dry modulus of rupture: 886 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
012	29.94	0.25	0.08	16.60	1.80	2.57
010	30.72	4.15	1.3	16.50	1.85	2.67
08	26.62	6.74	2.2	14.00	1.91	2.60
06	18.22	20.33	6.3	8.72	2.09	2.55
04	8.73	19.07	6.0	3.94	2.22	2.43
01	15.44	19.47	6.1	3.05	1.78	1.89

Fired modulus of rupture:

Cone 09, 2,660 pounds per square inch.

Cone 06, 1,623 pounds per square inch.

Fired specific impact strength:

Cone 09, 1.09 centimeter kilograms per square centimeter.

Cone 06, 1.17 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 06, 5,904 pounds per square inch.

Best firing range: Cone 012 to cone 04.

Overfiring temperature: Cone 02.

Pyrometric cone equivalent: Cone 3-4. Cones bloated.

Scumming: Scum is produced throughout the entire firing range of this material. Two pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: This material does not withstand the temperature necessary for the development of a good salt glaze.

Utilization: This material was being used for the production of drain tile, which represents its only commercial possibility. On firing the material develops a good red color at cone 06.

Highland County. Brick, hollow building block, and drain tile are produced from glacial drift at the plant of the Mowrystown Brick &

Tile Company at Mowrystown in White Oak Township. A section of the exposures in the pit is given below.

	Ft.	In.
Soil, not used	..	10
Glacial clay and silt, gray, low plasticity	3	0
Glacial clay and silt, mottled, with limestone and iron ore nodules. The iron content increases with depth	4	0
Bottom of pit.		

The material in this pit was sampled by A. E. MacGee of the National Bureau of Standards.

Sample No. 215

Tests of glacial clay from the pit of the Mowrystown Brick and Tile Company, Mowrystown, Highland County. (Tests by the Bureau of Standards)[1]

Chemical analysis

Loss on ignition	5.7
Silica, SiO_2	71.8
Alumina, Al_2O_3	13.6
Ferric oxide, Fe_2O_3	4.0
Lime, CaO	0.5
Magnesia, MgO	0.9
Titanic oxide, TiO_2	0.9
Total alkali chlorides computed as Na_2O	1.3
Sulphur, S	0.0
Total carbon, C	0.9

Oxide ratio

Alkalies, Na_2O basis	.09	Al_2O_3	1.00	SiO_2	5.28
CaO	.04			TiO_2	0.06
MgO	.07				
FeO	.26				
RO	.46				

Physical tests

Tempering water: About 24 per cent.
Drying linear shrinkage: About 6 to 7 per cent.
Drying volume shrinkage: About 20 to 21 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	0.0	0.0	14.4	Buff
Cone 06	0.0	0.0	15.2	Buff
Cone 04	0.8	2.3	12.4	Salmon
Cone 01	1.0	3.1	12.5	Brick red
Cone 4	3.0	8.8	10.7	Rich red
Cone 6	4.1	11.8	10.5	Rich red
Cone 8½	4.6	13.1	2.6	Mottled with gunmetal

Overburning temperature: About cone 8 to cone 9 (1,225°C. to 1,250°C. or 2,237°F. to 2,282°F.).

Best apparent burning range: Cone 04 to cone 7 (1,050°C. to 1,210°C. or 1,922°F. to 2,210°F.).

Total linear shrinkage at cone 8½: About 11 per cent.

Deformation temperature: Cone 13 to cone 14 (1,350°C. to 1,390°C. or 2,462°F. to 2,534°F.).

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

Huron County. At Monroeville in Ridgefield Township, Huron County, drain tile have been produced extensively at the plant of the Monroeville Clay Products Company, formerly owned by the Porous Products Corporation. The material utilized is a glacial drift varying in thickness from 3 to 6 feet. Limestone pebbles are scarce in the upper part of the deposit, but they increase in number downward and their presence practically limits the depth to which the material can be worked. A section in the pit is as follows:

	Ft.	In.
Soil	..	6
Silt and clay, yellowish, plastic, with a few pebbles of limestone	4	0
Bottom of pit.		

A sample was collected for testing on July 30, 1929, at ahe place where the above measurements were taken. The results of the tests are listed below:

Sample No. 7

Tests of glacial clays from the pit of the Monroeville Clay Products Company, Monroeville, Huron County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.65
Water, combined, H_2O+	4.04
Silica, SiO_2	67.18
Alumina, Al_2O_3	11.70
Titanic oxide, TiO_2	0.72
Phosphorus pentoxide, P_2O_5	0.09
Ferric oxide, Fe_2O_3	5.39
Ferrous oxide, FeO	0.75
Lime, CaO	2.54
Magnesia, MgO	1.43
Sodium oxide, Na_2O	0.53
Potassium oxide, K_2O	2.22
Manganese oxide, MnO	0.08
Sulphur trioxide, SO_3	trace
Carbon dioxide, CO_2	1.17
Carbon, organic, C	0.55

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .189 \\ Na_2O & .045 \\ CaO & .217 \\ MgO & .122 \\ FeO & .479 \\ MnO & .007 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 5.742 \\ TiO_2 & 0.061 \\ P_2O_5 & 0.008 \end{array}\right.$$

RO 1.059

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material is very plastic and sticky. The material tends to tear as it issues from the die.

Time of slaking: Over 24 hours.

Water of plasticity: 21.92 per cent.

Drying shrinkage:

Volume: 16.87 per cent.

Linear: 5.33 per cent.

Drying behavior: Extreme care is necessary in drying this material to avoid cracking.

Dry modulus of rupture: 655 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
012	29.92	0.05+	0.02+	16.50	1.81	2.58
010	30.58	0.18+	0.06+	16.60	1.84	2.65
08	29.98	0.56+	0.18+	16.40	1.82	2.60
06	29.26	2.24	0.7	15.62	1.87	2.67
04	23.39	6.21	2.0	11.92	1.96	2.57
02	16.88	13.20	4.2	8.15	2.11	2.54
1	10.38	20.20	6.3	4.37	2.25	2.55

Fired modulus of rupture:

Cone 06, 1,545 pounds per square inch.

Cone 1, 2,792 pounds per square inch.

Fired specific impact strength:

Cone 06, 1.25 centimeter kilograms per square centimeter.

Cone 1, 1.41 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 2, 14,285 pounds per square inch. This material is vitrified more than would be possible in a commercial kiln.

Best firing range: Cone 08 to cone 1.

Overfiring temperature: Cone 3.

Pyrometric cone equivalent: Cone 6.

Scumming: Scum occurs on all trials fired to cone 02 and lower but scum is not apparent on trials fired above cone 02. Three pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: This material does not withstand the temperature necessary for the production of a good salt glaze.

Utilization: This material was being used for the production of drain tile. It can be used also as a bond clay where extreme plasticity and low P. C. E. are required. On firing the material develops a good red color at cone 02.

Glacial drift is the raw material used in the production of drain tile and common brick at the plant of E. Bigelow Company, located at New London in New London Township. The material is taken from two pits located near the plant. The part which constitutes approximately one-third of the mixture is a very sandy glacial drift which occurs in a bed about 7 feet in thickness. It is used with a more plastic drift which occurs in a bed about 4½ feet in thickness and which is secured from a second pit. The more plastic variety is relatively free from pebbles of any kind although these impurities appear at greater depth. A. E. MacGee of the National Bureau of Standards sampled the material utilized in this plant.

Sample No. 216

Tests of glacial clay from the pit of E. Bigelow Company, New London, Huron County. (Tests by the Bureau of Standards)[1]

Chemical analysis				*Oxide ratio*			
Loss on ignition	8.0	K_2O	.16				
Silica, SiO_2	63.0	Na_2O	.04				
Alumina, Al_2O_3	15.0	CaO	.09	Al_2O_3	1.00	SiO_2	4.20
Ferric oxide, Fe_2O_3	6.3	MgO	.10			TiO_2	0.06
Lime, CaO	1.3	FeO	.38				
Magnesia, MgO	1.6		—				
Titanic oxide, TiO_2	0.9	RO	.77				
Sodium oxide, Na_2O	0.6						
Potassium oxide, K_2O	2.4						
Sulphur, S	0.0						
Total carbon, C	0.6						

Physical tests

Tempering water: About 30 per cent.
Drying linear shrinkage: About 10 per cent.
Drying volume shrinkage: About 33 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	1.7	4.9	12.3	Brick red
Cone 06	1.5	4.4	11.7	Brick red
Cone 04	4.4	12.5	6.4	Red
Cone 03	8.9	24.4	2.5	Red
Cone 01	9.4	25.7	1.8	Red

Overburning temperature: Cone 1 (1,125°C. or 2,057°F.).

Best apparent burning range: Cone 06 to cone 02 (1,005°C. to 1,095°C. or 1,841°F. to 2,003°F.).

Total linear shrinkage at cone 01: About 19 to 20 per cent.

Deformation temperature: Cone 10 (1,260°C. or 2,300°F.).

Logan County. Glacial drift has been utilized for a number of years at the plant now owned by the West Mansfield Clay Products Company and located at West Mansfield in Bokes Creek Township. Drain tile and hollow building block are the chief products. The exposures in the pit are as described below:

	Ft.	In.
Soil	..	8
Clay and silt, gray	1	10
Silt and clay, gray, somewhat calcareous, with a few pebbles	2	6

At greater depths than described in this section the pebbles embedded in the material increase in number to such an extent that it can not be

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

utilized successfully. A sample of the material described above, having a thickness of 5 feet, was secured on June 7, 1929.

Sample No. 11

Tests of glacial clay from the pit of the West Mansfield Clay Products Company, West Mansfield, Logan County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	2.32
Water, combined, H_2O+	4.70
Silica, SiO_2	61.61
Alumina, Al_2O_3	14.46
Titanic, oxide, TiO_2	0.72
Phosphorus pentoxide, P_2O_5	0.22
Ferric oxide, Fe_2O_3	5.29
Ferrous oxide, FeO	1.16
Lime, CaO	2.55
Magnesia, MgO	1.36
Sodium oxide, Na_2O	0.47
Potassium oxide, K_2O	2.35
Manganese oxide, MnO	0.18
Sulphur, S	0.03
Carbon dioxide, CO_2	1.82
Carbon, organic, C	0.80

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .163 \\ Na_2O & .033 \\ CaO & .176 \\ MgO & .094 \\ FeO & .409 \\ MnO & .012 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 4.261 \\ TiO_2 & 0.049 \\ P_2O_5 & 0.015 \end{array}\right.$$

$$RO \quad .887$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: The material is very plastic and sticky. A good column is extruded from the die.

Time of slaking: 72.1 minutes.

Water of plasticity: 25.83 per cent.

Drying shrinkage:

Volume: 22.87 per cent.

Linear: 7.10 per cent.

Drying behavior: Extreme care is necessary in drying this material to prevent cracking.

Dry modulus of rupture: 674 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
012	33.40	0.00	0.0	19.10	1.78	2.67
010	32.64	1.60	0.5	18.10	1.81	2.70
08	30.52	3.95	1.3	16.50	1.85	2.79
06	24.47	12.13	3.9	12.14	2.01	2.66
04	12.06	20.00	6.3	5.44	2.22	2.53
02	8.85	22.03	6.9	3.92	2.27	2.48
01	7.25	23.04	7.2	3.16	2.29	2.46

Fired modulus of rupture:

Cone 06, 1,888 pounds per square inch.

Cone 01, 2,873 pounds per square inch.

Fired specific impact strength:

Cone 06, 1.25 centimeter kilograms per square centimeter.

Cone 1, 1.18 centimeter kilograms per square centimeter.

Fired crushing strength:

Cone 1, 13,105 pounds per square inch.

These trials were fired so that material was slightly glassy.

Best firing range: Cone 010 to cone 01.

Overfiring temperature: Cone 2.

Pyrometric cone equivalent: Cone 6. Cones bloated.

Scumming: Scum occurs on all trials fired from cone 010 to cone 01. No scum occurs on trials fired at cone 012. One pound of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: This material does not withstand the temperature necessary for the development of a good salt glaze.

Utilization: This material was being used for the manufacture of drain tile and simple hollow tile shapes. Drain tile is about the only commercial possibility. On firing the material develops a good red color at cone 04.

Lucas County. The Collinwood Brick and Clay Company of Toledo utilizes glacial drift in the manufacture of common brick. The material was sampled by A. E. MacGee of the National Bureau of Standards.

Sample No. 217

Tests of glacial clay from the pit of the Collinwood Brick & Clay Company, Toledo, Lucas County. (Tests by the Bureau of Standards)[1]

Chemical analysis

Loss on ignition	10.7
Silica, SiO_2	53.7
Alumina, Al_2O_3	10.3
Ferric oxide, Fe_2O_3	5.0
Lime, CaO	9.5
Magnesia, MgO	4.0
Titanic oxide, TiO_2	0.7
Sodium oxide, Na_2O	0.7
Potassium oxide, K_2O	2.0
Sulphur, S	0.2
Total carbon, C	3.0

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .19 \\ Na_2O & .07 \\ CaO & .92 \\ MgO & .39 \\ FeO & .44 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 5.21 \\ TiO_2 & 0.07 \end{array}\right.$$

$$RO \quad 2.01$$

Physical tests

Tempering water: About 25 per cent.

Drying linear shrinkage: About 5 to 6 per cent.

Drying volume shrinkage: About 17 to 18 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	0.0	0.0	20.9	Tan
Cone 06½	0.8	2.4	24.7	Cream
Cone 04	1.6	4.8	20.1	Tan
Cone 1	7.9	21.9	6.3	Gray
Cone 3	8.1	22.4	0.1	Buff

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

Overburning temperature: Cone 2 (1,135°C. or 2,075°F.).

Best apparent burning range: Cone 08 to cone 01 (945°C. to 1,110°C. or 1,733°F. to 2,030°F.).

Total linear shrinkage at cone 3: About 13 to 14 per cent.

Deformation temperature: Cone 3 to cone 4 (1,145°C. to 1,165°C. or 2,093°F. to 2,129°F.).

Madison County. Common brick and drain tile are produced from glacial drift by the Madison Tile Company at London. The following is a description of the exposures in the pit.

	Ft.	In.
Soil, very dark	1	6
Silt and clay, yellowish, with some pebbles and concretions of limestone	3	6
Bottom of pit.		

Some brick have been produced at this plant but drain tile in sizes up to 2 feet in diameter are the chief product. The glacial drift exposed in the pit was sampled by A. E. MacGee of the National Bureau of Standards.

Sample No. 218

Tests of glacial clay from the pit of the Madison Tile Company, London, Madison County. (Tests by the Bureau of Standards)[1]

Chemical analysis

Loss on ignition	7.7
Silica, SiO_2	65.5
Alumina, Al_2O_3	13.5
Ferric oxide, Fe_2O_3	5.5
Lime, CaO	1.4
Magnesia, MgO	0.8
Titanic oxide, TiO_2	0.8
Sodium oxide, Na_2O	0.7
Potassium oxide, K_2O	2.3
Sulphur, S	0.0
Total carbon, C	1.5

Oxide ratio

K_2O	.17				
Na_2O	.05			SiO_2	4.85
CaO	.10	Al_2O_3	1.00		
MgO	.06			TiO_2	0.06
FeO	.37				
RO	.75				

Physical tests

Tempering water: About 30 per cent.

Drying linear shrinkage: About 11 to 12 per cent.

Drying volume shrinkage: About 38 to 39 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	0.8	2.4	13.3	Reddish buff
Cone 06	1.8	5.4	14.2	Reddish buff
Cone 04	5.4	15.3	6.9	Red
Cone 03	5.8	16.3	5.8	Red
Cone 02	6.5	18.3	3.9	Smoky red
Cone 1	6.8	19.0	1.6	Gun metal
Cone 3	5.8	16.5	1.1	Red
Cone 5	4.7	13.4	0.8	Red

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

Overburning temperature: Cone 3 (1,145°C. or 2,093°F.).

Best apparent burning range: Cone 04 to cone 01 (1,050°C. to 1,110°C. or 1,922°F. to 2,030°F.).

Total linear shrinkage at cone 1: About 18 to 19 per cent.

Deformation temperature: Cone 9 to cone 10 (1,250°C. to 1,260°C. or 2,282°F. to 2,300°F.).

Meigs County. Drain tile have been manufactured from alluvial silts and clays at the Rutland Tile Works at Rutland. The following results were secured from tests of a sample of the material collected by A. E. MacGee of the National Bureau of Standards.

Sample No. 219

Tests of alluvial clay from the pit of the Rutland Tile Works, Rutland, Meigs County. (Tests by the Bureau of Standards)[1]

Chemical analysis

Loss on ignition	7.7
Silica, SiO_2	56.9
Alumina, Al_2O_3	20.9
Ferric oxide, Fe_2O_3	4.1
Lime, CaO	2.2
Magnesia, MgO	2.3
Titanic oxide, TiO_2	1.2
Total alkali chlorides computed as Na_2O	2.5
Sulphur, S	0.1
Total carbon, C	0.6

Oxide ratio

Alkalies, Na_2O basis	.12	Al_2O_3	1.00	SiO_2	2.72
CaO	.10			TiO_2	0.06
MgO	.11				
FeO	.18				
RO	.51				

Physical tests

Tempering water: About 25 per cent.

Drying linear shrinkage: About 5 to 6 per cent.

Drying volume shrinkage: About 18 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	1.0	3.0	16.9	Buff
Cone 06	3.7	10.8	15.9	Buff
Cone 04	6.9	19.2	8.9	Tan
Cone 03	12.5	33.1	2.3	Red
Cone 02	8.3	22.9	6.2	Brick red
Cone 01	11.9	31.6	.7	Rich red
Cone 1	10.3	27.7	.1	Red

Overburning temperature: Cone 1 (1,125°C. or 2,057°F.).

Best apparent burning range: Cone 04 to cone 02 (1,050°C. to 1,095°C. or 1,922°F. to 2,003°F.).

Total linear shrinkage at cone 01: About 17 to 18 per cent.

Deformation temperature: Cone 6 to cone 7 (1,190°C. to 1,210°C. or 2,174°F. to 2,210°F.).

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

Mercer County. Common brick for local trade are made from glacial drift at the plant of the Celina Brick Company located near Celina in the east central part of Section 36, Jefferson Township. The material, which is a sandy glacial silt with some clay, is stripped to an average depth of about 1 foot 8 inches. Below this surface layer the drift contains numerous pebbles of limestone and foreign rock which render it useless for ceramic purposes. The green brick are dried on open air racks and fired with wood. The capacity of the plant is about 25,000 brick per day. The surface material used at this place, having a thickness of about 1 foot 8 inches, was sampled on June 6, 1929, and was submitted for testing with the results listed below:

Sample No. 3

Tests of glacial clay from the pit of the Celina Brick Company, Celina, Mercer County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.63
Water, combined, H_2O+ ..	3.96
Silica, SiO_2	71.80
Alumina, Al_2O_3	12.35
Titanic oxide, TiO_2	0.88
Phosphorus pentoxide, P_2O_5	0.20
Ferric oxide, Fe_2O_3	2.73
Ferrous oxide, FeO	0.90
Lime, CaO	0.61
Magnesia, MgO	1.36
Sodium oxide, Na_2O	0.46
Potassium oxide, K_2O	2.31
Manganese oxide, MnO	0.12
Sulphur, S	0.01
Carbon dioxide, CO_2	0.32
Carbon, organic, C	0.60

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .187 \\ Na_2O & .037 \\ CaO & .049 \\ MgO & .110 \\ FeO & .272 \\ MnO & .010 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 5.814 \\ TiO_2 & 0.071 \\ P_2O_5 & 0.016 \end{array}\right.$$

$$RO \quad .665$$

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material is very plastic and works excellently in the die.
Time of slaking: Over 48 hours.
Water of plasticity: 23.73 per cent.
Drying shrinkage:
Volume: 13.02 per cent.
Linear: 4.16 per cent.
Drying behavior: Extreme care is necessary in drying this material to avoid cracking.
Dry modulus of rupture: 307 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
06	31.54	10.32	3.3	17.42	1.81	2.65
04	23.20	15.62	5.0	11.58	1.99	2.59
02	19.51	18.33	5.8	9.43	2.08	2.57
1	15.71	21.39	6.7	7.33	2.16	2.58
3	11.69	24.80	7.7	5.26	2.23	2.53
5	7.06	25.00	7.7	3.12	2.25	2.28
7	4.98	23.09	7.2	2.26	2.21	2.33

Fired modulus of rupture:
Cone 02, 1,452 pounds per square inch.
Cone 5, 3,041 pounds per square inch.

Fired specific impact strength:
Cone 03, 1.29 centimeter kilograms per square centimeter.
Cone 4, 1.23 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 5, 11,980 pounds per square inch.

Best firing range: Cone 06 to cone 5.

Overfiring temperature: Cone 7.

Pyrometric cone equivalent: Cone 10.

Scumming: No scum develops throughout the firing range of this material.

Salt glazing: A good salt glaze is produced at both 2,100°F. and 2,050°F. The color of the glaze produced at 2,100°F. is a yellowish brown stain on a pinkish gray background. The color of the glaze produced at 2,050°F. has a grayish brown background with some yellowish green shades.

Utilization: This material was being used for the production of common brick. It can be used also for face brick and hollow tile. The fired material develops a good red color at about cone 1.

Muskingum County. A very fine-textured alluvial material known as Minford silt is used in part for the production of flower pots by the Zane Pottery Company at South Zanesville in Section 13, Springfield Township. In addition Homewood shale also supplies a part of the raw material used in this plant. The alluvial material exposed in the pit is somewhat variable in thickness but averages about 3½ feet. It is overlain with a fine-grained reddish-colored sand which is removed by stripping, and it is underlain with shale. The material was sampled for chemical analysis and other tests by A. E. MacGee of the National Bureau of Standards.

Sample No. 220

Tests of Minford clay from the pit of the Zane Pottery Company, near Zanesville, Muskingum County. (Tests by the Bureau of Standards)[1]

Chemical analysis

Loss on ignition	9.7
Silica, SiO_2	52.3
Alumina, Al_2O_3	22.5
Ferric oxide, Fe_2O_3	6.7
Lime, CaO	2.2
Magnesia, MgO	2.2

Oxide ratio

Alkalies, Na_2O basis	.15	Al_2O_3	1.00	SiO_2	2.32
CaO	.10			TiO_2	0.05
MgO	.10				
FeO	.26				

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

Chemical analysis		*Oxide ratio*	
Titanic oxide, TiO_2	1.1		
Total alkali chlorides computed as Na_2O	3.4	RO	.61
Sulphur, S	0.0		
Total carbon, C	0.3		

Physical tests

Tempering water: About 30 per cent.
Drying linear shrinkage: About 7 to 8 per cent.
Drying volume shrinkage: About 24 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	4.6	13.2	10.4	Light red
Cone 06	8.3	22.8	3.5	Light red
Cone 04	10.5	28.3	.9	Red
Cone 01	9.6	26.2	1.2	Red
Cone 1	10.6	28.6	1.2	Gray gun metal

Overburning temperature: Cone 01 (1,110°C. or 2,030°F.).

Best apparent burning range: Cone 010 to cone 06 (890°C. to 1,005°C. or 1,634°F. to 1,841°F.).

Total linear shrinkage at cone 1: About 18 per cent.

Deformation temperature: Cone 12 (1,310°C. or 2,390°F.).

Surface deposits of probable eolian origin are present on the upper slopes of the hills facing the Muskingum River. In places this material is a fine-grained sand well adapted for molding purposes. Along the river valley north of Zanesville it is a reddish-brown silty clay with varying amounts of fine-grained sand. The underlying bedrock is generally an arenaceous shale. W. L. Bunting of Zanesville has worked surface deposits of this type to a depth of 2 to 4 feet in the vicinity of Madden Station on the Wheeling & Lake Erie Railroad. A composite sample from three pits on neighboring hills near Madden was collected by A. E. MacGee of the National Bureau of Standards.

Sample No. 221

Tests of surface clay from property of W. L. Bunting near Madden Station, Muskingum Township, Muskingum County. (Tests by Bureau of Standards)[1]

Chemical analysis		*Oxide ratio*					
Loss on ignition	6.7	Alkalies, Na_2O basis	.09	Al_2O_3	1.00	SiO_2	3.24
Silica, SiO_2	61.9	CaO	.01			TiO_2	0.05
Alumina, Al_2O_3	19.1	MgO	.07				
Ferric oxide, Fe_2O_3	6.3	FeO	.30				
Lime, CaO	0.1		—				
Magnesia, MgO	1.5	RO	.47				
Titanic oxide, TiO_2	1.1						
Total alkali chlorides computed as Na_2O	1.7						
Sulphur, S	0.0						
Total carbon, C	0.8						

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

Physical tests

Tempering water: About 30 per cent.
Drying linear shrinkage: About 6 to 7 per cent.
Drying volume shrinkage: About 21 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	0.6	1.7	21.6	Orange
Cone 6½	2.3	6.7	20.4	Orange
Cone 04	7.4	20.5	10.5	Tan
Cone 3	8.3	22.8	9.6	Brick red
Cone 6	10.1	27.3	6.8	Dark red
Cone 7	10.3	27.7	5.5	Dark red
Cone 8	9.5	25.9	4.0	Dark red
Cone 8½	8.2	22.7	0.3	Maroon
Cone 9	8.4	23.2	0.2	Maroon

Overburning temperature: Cone 8 to cone 9 (1,225°C. to 1,250°C. or 2,237°F. to 2,282°F.).

Best apparent burning range: Cone 04 to cone 7 ((1,050°C. to 1,210°C. or 1,922°F. to 2,210°F.).

Total linear shrinkage at cone 7: About 16 to 17 per cent.

Deformation temperature: Cone 14 to cone 15 (1,390°C. to 1,410°C. or 2,534°F. to 2,570°F.).

Paulding County. One of the largest ceramic plants in Paulding County is owned by the Haviland Clay Works Company and is located at Haviland in Blue Creek Township. The plant is well equipped throughout with a capacity of 35,000 4-inch drain tile a day. In addition to tile, which are manufactured in sizes ranging from 3 inches to 2 feet 6 inches in diameter, common brick and hollow block are also produced. The raw material is similar in character to that utilized extensively in the adjoining counties to the east and to the north. The material exposed in the pit is described below:

	Ft.	In.
Soil	..	8
Silty clay, dark, plastic	2	6
Silty clay, with some limestone pebbles, forms the bottom of the pit	..	..

The depth to which the material can be used is determined by the presence of limestone pebbles which increase in number downward. A sample of the material utilized in the plant, consisting of the soil and the 2-foot 6-inch bed of silty clay underlying it, was cut on June 5, 1929, and was submitted for testing. The chemical composition and results of other tests are as follows:

Sample No. 6

Tests of glacial clay from the pit of the Haviland Clay Works Company, Haviland, Paulding County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	2.85
Water, combined, H_2O+ ..	4.43
Silica, SiO_2	62.62
Alumina, Al_2O_3	13.33
Titanic oxide, TiO_2	0.77
Phosphorus pentoxide, P_2O_5	0.21
Ferric oxide, Fe_2O_3	5.86
Ferrous oxide, FeO	1.52
Lime, CaO	1.80
Magnesia, MgO	2.05
Sodium oxide, Na_2O	0.72
Potassium oxide, K_2O	2.90
Manganese oxide, MnO ..	0.06
Sulphur, S	0.01
Carbon dioxide, CO_2	0.60
Carbon, organic, C	0.55

Oxide ratio

K_2O	.218				
Na_2O	.054			SiO_2	4.698
CaO	.135	Al_2O_3	1.00	TiO_2	0.058
MgO	.154			P_2O_5	0.015
FeO	.524				
MnO	.004				
RO	1.089				

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material is very plastic and sticky. A good column is extruded from the die.

Time of slaking: 48 hours.

Water of plasticity: 29.88 per cent.

Drying shrinkage:

Volume: 29.20 per cent.

Linear: 8.91 per cent.

Drying behavior: Extreme care is necessary in drying this material to avoid cracking.

Dry modulus of rupture: 945 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
012	28.51	1.27+	0.42+	16.30	1.75	2.45
010	25.93	3.52	1.2	13.80	1.86	2.52
08	22.00	8.39	2.7	11.30	1.95	2.58
06	16.16	13.18	4.2	8.09	2.05	2.46

Fired modulus of rupture:

Cone 010, 2,701 pounds per square inch.

Cone 06, 1,300 pounds per square inch.

Fired specific impact strength:

Cone 09, 1.03 centimeter kilograms per square centimeter.

Cone 04, 1.16 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 06, 4,099 pounds per square inch.

Best firing range: Cone 012 to cone 06.

Overfiring temperature: Cone 04.

Pyrometric cone equivalent: Cone 5-6.

Scumming: Scum is not apparent on trials fired to cone 012 and lower but scum occurs on all trials fired above cone 012. Two pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: This material does not withstand the temperature necessary for the development of a good salt glaze.

Utilization: This material was being used chiefly for the manufacture of drain tile although some common brick and hollow tile are also produced. On firing the material develops a good red color at cone 06.

Pike County. Drain tile were formerly produced from the so-called Minford silt at a small plant operated by H. E. Albert and located near Beaver in the central part of Section 4, Marion Township. The material, which is widely distributed in this vicinity, is a fine-grained, thinly-laminated silty clay of a bluish gray color. It is generally uniform in texture throughout the deposit but in places thin lenses of ferruginous sand occur. In the old pit situated a short distance south of the plant the material has been utilized to a depth of about 7 feet, while in a second pit located east of the plant the material has been excavated to a depth of about 12 feet. A E. MacGee of the National Bureau of Standards sampled the material in the south pit for chemical analysis and other tests.

Sample No. 222

Tests of Minford alluvial clay from pit of H. E. Albert, Beaver, Pike County. (Tests by the Bureau of Standards)[1]

Chemical analysis

Loss on ignition	6.0
Silica, SiO_2	70.8
Alumina, Al_2O_3	14.3
Ferric oxide, Fe_2O_3	4.7
Lime, CaO	0.5
Magnesia, MgO	0.9
Titanic oxide, TiO_2	1.2
Total alkali chlorides computed as Na_2O	0.5
Sulphur, S	0.2
Total carbon, C	0.3

Oxide ratio

Alkalies, Na_2O basis	.03	Al_2O_3	1.00	SiO_2	4.95
CaO	.03			TiO_2	0.08
MgO	.06				
FeO	.30				
RO	.42				

Physical tests

Tempering water: About 27 per cent.

Drying linear shrinkage: About 8 per cent.

Drying volume shrinkage: About 26 per cent.

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	0.0	0.0	15.8	Buff
Cone 06	1.0	3.1	14.8	Reddish buff
Cone 04	3.5	10.0	10.0	Salmon
Cone 03	4.8	13.7	8.8	Brick red
Cone 3½	6.1	17.2	4.3	Rich red
Cone 4	6.7	18.8	2.8	Rich red
Cone 5	6.6	18.5	4.4	Dark red
Cone 6	5.2	14.9	1.1	Maroon
Cone 7½	5.5	15.5	2.7	Maroon-gun metal
Cone 9	4.4	12.6	0.3	Maroon

Overburning temperature: Cone 6 (about) (1,190°C. or 2,174°F.).

Best apparent burning range: Cone 04 to cone 4 (1,050°C. to 1,165°C. or 1,922°F. to 2,129°F.).

Total linear shrinkage at cone 4: About 14 to 15 per cent.

Deformation temperature: Cone 9 (1,250°C. or 2,282°F.).

Other analyses of Minford silt from Pike County.

	1	2
Water, hydroscopic, H_2O- / Water, combined, H_2O+	5.13	5.10
Silica, SiO_2	53.40	57.35
Alumina, Al_2O_3	28.08	24.16
Titanic oxide, TiO_2	0.75	0.80
Phosphorus pentoxide, P_2O_5	0.10	0.11
Ferric oxide, Fe_2O_3	4.50	5.25
Ferrous oxide, FeO	....	....
Lime, CaO	0.66	0.48
Magnesia, MgO	1.94	1.46
Sodium oxide, Na_2O	trace	0.10
Potassium oxide, K_2O	4.40	4.84
Manganese oxide, MnO	0.02	0.03
Sulphur, S	....	....
Carbon dioxide, CO_2	0.30	None
Carbon, organic, C	0.50	0.10

1. Sample taken by Wilber Stout and Downs Schaaf, 1928, east central Section 25, Union Township, Pike County. Bull. Geol. Soc. America, Vol. 42, pp. 667-668, 1931.

2. Sample taken by Wilber Stout and Downs Schaaf, 1928, northeast quarter Section 18, Seal Township, Pike County. Bull. Geol. Soc. America, Vol. 42, pp. 667-668, 1931.

Scioto County. Materials of alluvial origin are widely distributed along the major valleys in Scioto County. Alluvial materials of very fine grain and high plasticity occur along the old valley which extends from Sciotoville north through Porter, Harrison, and Madison townships. The deposits are well exposed in the cut of the Chesapeake and Ohio Railroad at Minford, Madison Township, and have been named the *Minford silt.*[1] A description of the deposits is as follows:

[1] Stout, Wilber, and Schaaf, Downs, Minford silts of southern Ohio, Bull. Geol. Soc. America, Vol. 42, pp. 663-672, 1931.

	Ft.	In.
Clay, chocolate-tinted, fine-grained, laminated, highly plastic	22	0
Clay, yellowish, ferruginous	1	6
Sand, coarse	..	6
Sand, fine-grained, and silt	3	0

A sample of the material above the 6-inch bed of coarse sand was secured in 1929 and was submitted for testing.

Sample No. 2

Tests of Minford alluvial clay near Minford, Madison Township

Chemical analysis *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	2.52
Water, combined, H_2O+	5.27
Silica, SiO_2	55.91
Alumina, Al_2O_3	17.30
Titanic oxide, TiO_2	1.00
Phosphorus pentoxide, P_2O_5	0.18
Ferric oxide, Fe_2O_3	8.58
Ferrous oxide, FeO	1.33
Lime, CaO	0.90
Magnesia, MgO	2.41
Sodium oxide, Na_2O	0.45
Potassium oxide, K_2O	3.25
Manganese oxide, MnO	0.06
Sulphur, S	0.04
Carbon dioxide, CO_2	0.72
Carbon, organic, C	0.25

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .188 \\ Na_2O & .026 \\ CaO & .052 \\ MgO & .139 \\ FeO & .523 \\ MnO & .003 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 3.232 \\ TiO_2 & 0.058 \\ P_2O_5 & 0.010 \end{array}\right.$$

RO .931

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material is very plastic and sticky. A laminated and featheredged column is extruded from the die.

Time of slaking: 44.97 minutes.

Water of plasticity: 29.31 per cent.

Drying shrinkage:

Volume: 25.86 per cent.

Linear: 7.97 per cent.

Drying behavior: Great care is necessary in drying this material to avoid cracking.

Dry modulus of rupture: 383 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
012	34.14	0.05	0.02	19.90	1.72	2.62
010	30.00	6.68	2.2	16.30	1.84	2.63
08	14.15	17.08	5.4	6.98	2.04	2.38
06	11.48	21.90	6.8	5.30	2.17	2.45

Fired modulus of rupture:

Cone 09, 1,790 pounds per square inch.

Cone 06, 5,284 pounds per square inch.

Fired specific impact strength:

Cone 09, 0.909 centimeter kilograms per square centimeter.

Cone 06, 1.37 centimeter kilograms per square centimeter.

Fired crushing strength: Cone 06, 4,623 pounds per square inch.

Best firing range: Cone 010 to cone 06.

Overfiring temperature: Cone 04. Cones bloated.

Pyrometric cone equivalent: Cone 14-15.

Scumming: Scum is produced throughout the entire firing range of this material. Six pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: A good salt glaze can not be produced on this material as it does not withstand the necessary temperature.

Utilization: This material was not being utilized for ceramic purposes. It is not recommended except as a bond material.

A sample of Minford silt was secured by Wilber Stout and Downs Schaaf in 1928 from upper layer in railroad cut at Minford, south central Section 33, Madison Township, Scioto County.[1]

Water, hydroscopic, H_2O-	2.77
Water combined, H_2O+	3.23
Silica, SiO_2	50.02
Alumina, Al_2O_3	23.10
Titanic oxide, TiO_2	0.74
Phosphorus pentoxide, P_2O_5	0.75
Ferric oxide, Fe_2O_3	7.08
Ferrous oxide, FeO	1.16
Lime, CaO	0.86
Magnesia, MgO	2.80
Sodium oxide, Na_2O	3.43
Potassium oxide, K_2O	4.40
Manganese oxide, MnO	0.05
Sulphur, S	0.015
Carbon dioxide, CO_2	0.04
Carbon, organic, C	0.05

Tuscarawas County. Alluvial silts and clays were formerly utilized for the production of drain tile at the plant of Shepfer & Moomaw Brothers, at Sugar Creek, Tuscarawas County. Material similar to that

[1] Geol. Soc. America Bull., Vol. 42, pp. 667-8, 1931.

formerly utilized was secured at this locality by A. E. MacGee of the National Bureau of Standards.

Sample No. 223

Tests of alluvial clay from pit of Shepfer & Moomaw Bros., Sugar Creek, Tuscarawas County. (Tests by Bureau of Standards)[1]

Chemical analysis		*Oxide ratio*					
Loss on ignition	5.9	Alkalies, Na_2O basis	.12	Al_2O_3	1.00	SiO_2	4.21
Silica, SiO_2	68.3	CaO	.04			TiO_2	0.06
Alumina, Al_2O_3	16.2	MgO	.07				
Ferric oxide, Fe_2O_3	4.7	FeO	.26				
Lime, CaO	0.6						
Magnesia, MgO	1.1	RO	.49				
Titanic oxide, TiO_2	1.0						
Total alkali chlorides computed as Na_2O	1.9						
Sulphur, S	0.0						
Total carbon, C	1.0						

Physical tests

Tempering water: About 27 per cent.
Drying linear shrinkage: About 7 per cent.
Drying volume shrinkage: About 22 to 23 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	0.6	1.8	17.2	Orange
Cone 06	1.9	5.5	16.8	Orange
Cone 04	4.9	14.0	10.9	Red
Cone 3½	6.7	18.8	3.6	Dark red
Cone 4	7.1	19.9	3.4	Rich red
Cone 5	6.2	17.5	6.6	Red
Cone 7	6.7	18.7	5.2	Dark red

Overburning temperature: Cone 9 (1,250°C. or 2,282°F.)
Best apparent burning range: Cone 04 to 7 (1,050°C. to 1,210°C. or 1,922°F. to 2,210°F.)
Total linear shrinkage at cone 4: About 14 per cent.
Deformation temperature: Cone 12 (1,310°C. or 2,390°F.)

Williams County. Surface materials of glacial origin are utilized for the manufacture of drain tile at Stryker, Springfield Township, in the plant owned and operated by the Stryker Drain Tile Company. The following is a description of the deposits:

	Ft.	In.
Soil	..	6
Silt and clay, yellowish, generally free from pebbles	2	0
Silt and clay, gray, calcareous, with limestone pebbles, forms bottom of pit	..	..

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

The 2-foot layer of material is loaded with a small power shovel. The lime content of the material increases at greater depth and renders it unfit for ceramic purposes. A sample of the 2-foot bed was taken on June 5, 1929, and was submitted for testing with the following results:

Sample No. 10

Tests of glacial clay from the pit of the Stryker Drain Tile Company, Stryker, Springfield Township, Williams County

Chemical analysis — *Downs Schaaf, analyst*

Water, hydroscopic, H_2O-	1.24
Water, combined, H_2O+..	3.44
Silica, SiO_2..............	58.63
Alumina, Al_2O_3..........	11.22
Titanic oxide, TiO_2........	0.70
Phosphorus pentoxide, P_2O_5	0.16
Ferric oxide, Fe_2O_3........	4.65
Ferrous oxide, FeO.......	1.32
Lime, CaO..............	6.50
Magnesia, MgO..........	2.95
Sodium oxide, Na_2O.......	0.55
Potassium oxide, K_2O.....	2.40
Manganese oxide, MnO....	0.07
Sulphur, S..............	Trace
Carbon dioxide, CO_2......	5.90
Carbon, organic, C........	0.38

Oxide ratio

K_2O	.214				
Na_2O	.049			SiO_2	5.226
CaO	.579	Al_2O_3	1.00	TiO_2	0.062
MgO	.263			P_2O_5	0.014
FeO	.490				
MnO	.006				
RO	1.601				

Physical properties, determined by Chester R. Austin

Properties in green state

Workability: This material is very plastic and rather gummy. A very good column is extruded from the die.

Time of slaking: 24 hours.

Water of plasticity: 23.88 per cent.

Drying shrinkage:

Volume: 16.20 per cent.

Linear: 5.13 per cent.

Drying behavior: Extreme care is necessary in drying this material to prevent cracking.

Dry modulus of rupture: 762 pounds per square inch.

Firing behavior

Cone	Apparent porosity Per cent	Volume shrinkage Per cent	Calculated linear shrinkage Per cent	Absorption Per cent	Bulk specific gravity	Apparent specific gravity
012	36.50	1.25	0.42	21.70	1.68	2.65
010	37.60	0.44	0.14	22.40	1.69	2.70
08	37.71	0.35	0.12	22.30	1.69	2.72
06	36.62	0.24	0.08	21.71	1.69	2.68
04	33.90	2.76	0.90	20.10	1.71	2.62
02	28.25	10.15	3.30	15.32	1.88	2.64
1	17.61	16.12	5.00	8.12	2.07	2.54
3	1.69	25.94	8.00	0.75	2.28	2.31

Fired modulus of rupture:
Cone 06, 1,689 pounds per square inch.
Cone 1, 3,465 pounds per square inch.
Fired specific impact strength:
Cone 06, 1.21 centimeter kilograms per square centimeter.
Cone 1, 1.59 centimeter kilograms per square centimeter.
Fired crushing strength: Cone 1, 16,873 pounds per square inch.
Best firing range: Cone 04 to cone 1.
Overfiring temperature: Cone 2.
Pyrometric cone equivalent: Cone 3.

Scumming: Scum occurs on all trials fired from 012 to cone 1, but no scum is apparent on trials fired above cone 1. Two pounds of $BaCO_3$ per ton of material is necessary to prevent scumming.

Salt glazing: This material will not withstand the temperature necessary for the development of a good salt glaze.

Utilization: This material was being used for drain tile and because of its rather short firing range (cone 04 to cone 1) and extreme plasticity this use is probably its only commercial possibility. On firing the material develops a fair red color at cone 1.

Wyandot County. The Wyandot Clay Products Company produces drain tile, face brick, and hollow building block from glacial drift at the plant located at Upper Sandusky in Section 6, Crane Township. The raw material which supplies the plant is a glacial drift of somewhat variable character which contains small pebbles and nodules of limestone and foreign material. In the first pit the material utilized has a thickness of about 5 feet and is somewhat sandy in character. The material from this pit is mixed in about equal proportions with a more plastic drift from a second pit which has a depth of about 6½ feet. The resulting mixture is passed through a rotary dryer and dry pan and is then screened. The screened material was sampled by A. E. MacGee of the National Bureau of Standards.

Sample No. 224

Tests of glacial clay from the pit of the Wyandot Clay Products Company, Upper Sandusky, Wyandot County. (Tests by the Bureau of Standards)[1]

Chemical analysis

Loss on ignition	7.3
Silica, SiO_2	62.3
Alumina, Al_2O_3	13.6
Ferric oxide, Fe_2O_3	5.9
Lime, CaO	3.5
Magnesia, MgO	2.1
Titanic oxide, TiO_2	0.9
Sodium oxide, Na_2O	0.6
Potassium oxide, K_2O	2.4
Sulphur, S	0.0
Total carbon, C	1.3

Oxide ratio

K_2O	.18	Al_2O_3	1.00	SiO_2	4.58
Na_2O	.04			TiO_2	0.06
CaO	.26				
MgO	.15				
FeO	.39				
RO	1.02				

[1] Chemical analysis by J. F. Klekotka and physical properties by A. E. MacGee and W. C. O. White.

SUMMARY TABLE OF TEST BUREAU OF STANDARDS

Sample No.	GEOLOGIC CLASSIFICATION: System	Series or Formation	Subdivision or Member	Kind of material	FIRM (1926-1927)	LOCATION: Place	Section	Township	County	CHEMICAL ANALYSIS: Loss on Ignition	Silica, $Si O_2$	Alumina, $Al_2 O_3$	Ferric oxide, $Fe_2 O_3$	Lime, Cao	Magnesia, Mgo	Titanic oxide, TiO_2	Sodium oxide, $Na_2 O$	Potassium oxide, K_2O	Sulphur, S	Total carbon, C	OXIDE RATIO: Sum of $K_2 O$, Na_2O, CaO, MgO, FeO	$Al_2 O_3$	Sum of SiO_2, TiO_2, P_2O_5	PROPERTIES IN GREEN STATE: Tempering water, Per cent	Drying linear shrinkage, Per cent	Drying volume shrinkage, Per cent
200	Ordovician	Eden		Shale	Queen City Brick Co.	Fairmont Cincinnati			Hamilton	6.5	53.6	16.0	7.6	6.5	2.9	1.0	0.9	3.7	0.4	1.1	1.30	1.00	3.41	About 26	About 6	About 20
201	Devonian	Ohio	Chagrin	Shale	Collinwood Shale Brick & Supply Co.	Collinwood Cleveland		Euclid	Cuyahoga	6.0	57.1	19.6	8.0	0.6	1.8	1.0	0.7	3.7	0.8	0.6	.71	1.00	2.96	About 20	About 4 to 5	About 14 to 15
202	Mississippian	Bedford		Shale	Claycraft Mining & Brick Co.	Taylor		Jefferson	Franklin	7.0	59.4	17.2	8.9	0.5	1.5	1.2	0.2	2.9	0.0	0.6	.76	1.00	3.52	About 20	About 5 to 6	About 17 to 18
203	Mississippian	Cuyahoga		Shale	Peebles Paving Brick Co.	Portsmouth		Clay	Scioto	5.2	64.2	15.7	7.1	0.5	1.6	1.1	0.5	3.0	0.0	0.3	.76	1.00	4.16	About 20	About 3 to 4	About 12 to 13
205	Mississippian	Logan		Shale	Hanover Brick Co.	Hanover		Hanover	Licking	5.3	59.7	19.5	6.7	0.4	1.5	1.1	0.3	3.6	0.2	1.0	.60	1.00	3.11	About 23	About 4 to 5	About 15 to 16
204	Pennsylvanian	Pottsville	Anthony	Shale	Carlyle-Labold Co.	Portsmouth	12	Porter	Scioto	8.3	60.5	20.1	5.9	0.2	1.0	1.1	0.0	1.5	0.1	0.9	.39	1.00	3.06	About 25	About 5 to 6	About 18 to 19
206	Pennsylvanian	Allegheny	Clarion	Shale	Ludowici-Celadon Co.	New Lexington	7	Pike	Perry	6.4	60.6	17.6	7.2	0.7	0.8	1.0	0.5	3.0	0.2	1.0	.65	1.00	3.50	About 20	About 4	About 13
207	Pennsylvanian	Allegheny	Lower Freeport	Shale	Robinson Clay Products Co.	Malvern	20	Brown	Carroll	6.6	57.5	19.3	8.3	0.4	2.0	1.0	0.8	3.0	0.1	0.9	.70	1.00	3.03	About 22	About 3 to 4	About 10
208	Pennsylvanian	Conemaugh	Buffalo and Brush Creek	Shale	Summitville Brick Co.	Summitville	23	Franklin	Columbiana	6.2	60.8	18.0	7.2	0.5	1.5	1.0	0.7	2.6	0.0	0.6	.65	1.00	3.43	About 22	About 3 to 4	About 10 to 11
209	Pennsylvanian	Conemaugh	Cow Run	Shale	Ava Brick Co.	Ava	30	Buffalo	Noble	7.6	60.5	17.1	7.1	1.4	1.8	1.0	0.5	2.5	0.0	0.3	.73	1.00	3.59	About 20	About 4 to 5	About 15
210	Pleistocene			Silt and Clay	Lima Brick Co.	Lima	19	Bath	Allen	9.3	53.7	13.3	5.6	8.1	2.7	0.7	1.0	2.5	0.2	2.5	1.45	1.00	4.09	About 22	About 4 to 5	About 14 to 15
211	Recent			Alluvial Silt and Clay	F. H. Everal	Westerville		Blendon	Franklin	6.5	67.7	14.6	5.2	0.9	1.2	1.0	2.1*	....	0.1	0.7	.60	1.00	4.70	About 28	About 7 to 8	About 24
212	Recent			Alluvial Silt and Clay	Gallipolis Brick & Tile Co.	Gallipolis	23	Gallipolis	Gallia	7.9	63.3	18.3	5.2	0.3	1.5	1.1	2.1*	....	0.1	0.3	.46	1.00	3.52	About 27	About 7	About 22 to 23
213	Pleistocene			Glacial drift	Mt. Healthy Brick Co.	Mt. Healthy	32	Springfield	Hamilton	5.8	73.9	11.5	4.2	0.3	0.7	0.9	0.6	1.5	0.1	0.5	.59	1.00	6.50	About 30	About 8	About 26
214	Pleistocene			Glacial drift	Hancock Brick & Tile Co.	Findlay	30	Marion	Hancock	6.2	67.6	12.8	5.6	1.2	1.4	0.8	0.9	2.5	0.0	1.1	.86	1.00	5.34	About 27	About 7 to 8	About 23 to 24
215	Pleistocene			Glacial drift	Mowrystown Brick & Tile Co.	Mowrystown		Whiteoak	Highland	5.7	71.8	13.6	4.0	0.5	0.9	0.9	1.3*	....	0.0	0.9	.46	1.00	5.34	About 24	About 6 to 7	About 20 to 21
216	Pleistocene			Glacial drift	E. Bigelow Co.	New London		New London	Huron	8.0	63.0	15.0	6.3	1.3	1.6	0.9	0.6	2.4	0.0	0.6	.77	1.00	4.26	About 30	About 10	About 33
217	Pleistocene			Glacial drift	Collinwood Brick & Clay Co.	Toledo	13	Washington	Lucas	10.7	53.7	10.3	5.0	9.5	4.0	0.7	0.7	2.0	0.2	3.0	2.01	1.00	5.28	About 25	About 5 to 6	About 17 to 18
218	Pleistocene			Glacial drift	Madison Tile Co.	London		Union	Madison	7.7	65.5	13.5	5.5	1.4	0.8	0.8	0.7	2.3	0.0	1.5	.75	1.00	4.91	About 30	About 11 to 12	About 38 to 39
219	Recent			Alluvial Silt and Clay	Rutland Tile Works	Rutland		Rutland	Meigs	7.7	56.9	20.9	4.1	2.2	2.3	1.2	2.5*	....	0.1	0.6	.51	1.00	2.78	About 25	About 5 to 6	About 18
220	Pleistocene		Minford	Alluvial Silt and Clay	Zane Pottery Co.	South Zanesville	13	Springfield	Muskingum	9.7	52.3	22.5	6.7	2.2	2.2	1.1	3.4*	....	0.0	0.3	.61	1.00	2.37	About 30	About 7 to 8	About 24
221	Pleistocene			Eolian Silt and Clay	W. L. Bunting	Madden	-	Muskingum	Muskingum	6.7	61.9	19.1	6.3	0.1	1.5	1.1	1.7*	....	0.0	0.8	.47	1.00	3.29	About 30	About 6 to 7	About 21
222	Pleistocene		Minford	Alluvial Silt and Clay	H. E. Albert	Beaver	4	Marion	Pike	6.0	70.8	14.3	4.7	0.5	0.9	1.2	0.5*	....	0.2	0.3	.42	1.00	5.03	About 27	About 8	About 26
223	Recent			Alluvial Silt and Clay	Shepfer & Moomaw Bros.	Sugar Creek		Sugar Creek	Tuscarawas	5.9	68.3	16.2	4.7	0.6	1.1	1.0	1.9*	....	0.0	1.0	.49	1.00	4.27	About 27	About 7	About 22 to 23
224	Pleistocene			Glacial drift	Wyandot Clay Products Co.	Upper Sandusky	6	Crane	Wyandot	7.3	62.3	13.6	5.9	3.5	2.1	0.9	0.6	2.4	0.0	1.3	1.02	1.00	4.64	About 25	About 6 to 7	About 21 to 22

Sample No.	PROPERTIES AFTER FIRING: Maximum volume shrinkage: At Cone	Maximum volume shrinkage: Per cent	Maximum linear shrinkage: At Cone	Maximum linear shrinkage: Per cent	Minimum volume absorption: At Cone	Minimum volume absorption: Per cent	Overburning temperature: Cone	Overburning temperature: °F	Best apparent burning range	Deformation temperature: Cone	Deformation temperature: °F	Analyst	Physical properties by	Date of sampling	Sample No.
200	04	16.9	04	6.0	1	0.8	2	2075	Cone 04 to Cone 01	3	2093	J. F. Kleckotka	A. E. MacGee, W. C. O. White	Oct. 7, 1926	200
201	1	20.4	1	7.3	1	2.1	2	2075	Cone 06 to Cone 01	10	2300	J. F. Klekotka	A. E. MacGee, W. C. O. White	Oct. 22, 1926	201
202	02	19.8	02	7.1	4	0.6	8	2237	Cone 06 to Cone 1	13	2462	J. F. Klekotka	A. E. MacGee, W. C. O. White	Oct. 4, 1926	202
203	6	26.1	6	9.6	8	0.6	9	2282	Cone 04 to Cone 6	12	2390	J. F. Klekotka	A. E. MacGee, W. C. O. White	Oct. 8, 1926	203
205	1	25.7	1	9.4	4	0.9	5	2156	Cone 04 to Cone 1	12-13	2390-2462	J. F. Klekotka	A. E. MacGee, W. C. O. White	Oct. 15, 1926	205
204	8	24.5	8	8.9	9	1.9	8-9	2237-2282	Cone 04 to Cone 7	14	2534	J. F. Klekotka	A. E. MacGee, W. C. O. White	Oct. 9, 1926	204
206	4	24.6	4	9.0	4	2.5	6	2174	Cone 04 to Cone 3	11	2345	J. F. Klekotka	A. E. MacGee, W. C. O. White	Oct. 18, 1926	206
207	3	26.6	3	9.8	4	1.6	5	2156	Cone 06 to Cone 3	10-11	2300-2345	J. F. Klekotka	A. E. MacGee, W. C. O. White	Oct. 21, 1926	207
208	7	27.1	7	10.0	7	2.2	8	2237	Cone 04 to Cone 4	11	2345	J. F. Klekotka	A. E. MacGee, W. C. O. White	Oct. 20, 1926	208
209	04	21.3	04	7.7	3	1.1	4	2129	Cone 06 to Cone 2	10	2300	J. F. Klekotka	A. E. MacGee, W. C. O. White	Oct. 19, 1926	209
210	01	28.1	01	10.4	1	3.3	About Cone 2	2075	Cone 04 to Cone 01	3	2093	J. F. Klekotka	A. E. MacGee, W. C. O. White	Dec. 8, 1927	210
211	6	25.3	6	9.3	6	0.9	7-8	2210-2237	Cone 04 to Cone 4	10	2300	J. F. Klekotka	A. E. MacGee, W. C. O. White	Aug. 12, 1926	211
212	3½	24.5	3½	8.9	7	2.1	8	2237	Cone 04 to Cone 6	13	2462	J. F. Klekotka	A. E. MacGee, W. C. O. White	Aug. 27, 1926	212
213	8	24.1	8	8.8	9	0.1	8-9	2237-2282	Cone 04 to Cone 6	12	2390	J. F. Klekotka	A. E. MacGee, W. C. O. White	Nov. 21, 1927	213
214	1	21.6	1	7.8	5	1.1	About Cone 2	2075	Cone 04 to Cone 02	8	2237	J. F. Klekotka	A. E. MacGee, W. C. O. White	Dec. 7, 1927	214
215	8½	13.1	8½	4.6	8½	2.6	8-9	2237 to 2282	Cone 04 to Cone 7	13-14	2462-2534	J. F. Klekotka	A. E. MacGee, W. C. O. White	Aug. 25, 1926	215
216	01	25.7	01	9.4	01	1.8	1	2057	Cone 06 to Cone 02	10	2300	J. F. Klekotka	A. E. MacGee, W. C. O. White	Dec. 6, 1927	216
217	3	22.4	3	8.1	3	0.1	2	2075	Cone 08 to Cone 01	3-4	2093-2129	J. F. Klekotka	A. E. MacGee, W. C. O. White	Dec. 6, 1927	217
218	1	19.0	1	6.8	5	0.8	3	2093	Cone 04 to Cone 01	9-10	2282-2300	J. F. Klekotka	A. E. MacGee, W. C. O. White	Nov. 21, 1927	218
219	03	33.1	03	12.5	1	0.1	1	2057	Cone 04 to Cone 02	6-7	2174-2210	J. F. Klekotka	A. E. MacGee, W. C. O. White	Aug. 28, 1926	219
220	1	28.6	1	10.6	04	0.9	01	2030	Cone 010 to Cone 06	12	2390	J. F. Klekotka	A. E. MacGee, W. C. O. White	Aug. 20, 1926	220
221	7	27.7	7	10.3	9	0.2	8-9	2237-2282	Cone 04 to Cone 7	14-15	2534-2570	J. F. Klekotka	A. E. MacGee, W. C. O. White	Aug. 19, 1926	221
222	4	18.8	4	6.7	9	0.3	6	2174	Cone 04 to Cone 4	9	2282	J. F. Klekotka	A. E. MacGee, W. C. O. White	Aug. 26, 1926	222
223	4	19.9	4	7.1	4	3.4	9	2282	Cone 04 to Cone 7	12	2390	J. F. Klekotka	A. E. MacGee, W. C. O. White	Aug. 21, 1926	223
224	1	20.9	1	7.5	1	2.6	2	2075	Cone 04 to Cone 1	3	2093	J. F. Klekotka	A. E. MacGee, W. C. O. White	Dec. 6, 1927	224

* Total alkali chlorides computed as K_2O.

Physical tests

Tempering water: About 25 per cent.
Drying linear shrinkage: About 6 to 7 per cent.
Drying volume shrinkage: About 21 to 22 per cent.

Burning behavior

Burning temperature	Linear shrinkage Per cent	Volume shrinkage Per cent	Volume absorption Per cent	Color
Cone 08	0.6	1.8	15.9	Light red
Cone 06½	1.1	3.3	16.2	Salmon
Cone 04	3.8	11.1	9.6	Tan
Cone 03	5.4	15.3	6.7	Red
Cone 02	4.9	14.0	4.6	Brick red
Cone 01	7.4	20.6	3.0	Brick red
Cone 1	7.5	20.9	2.6	Brick red

Overburning temperature: Cone 2 (1,135°C. or 2,075°F.).

Best apparent burning range: Cone 04 to cone 1 (1,050°C. to 1,125°C. or 1,922°F. to 2,057°F.).

Total linear shrinkage at cone 1: About 14 per cent.

Deformation temperature: Cone 3 (1,145°C. or 2,093°F.).

CHAPTER IV

TESTING PROCEDURE[1]

By Chester R. Austin

GENERAL PROCEDURE

The procedure followed in testing the clays included in this report was as recommended by the American Ceramic Society and published in the Journal of that society, June, 1928.

The samples as received were ground in a Denver No. 2 jaw crusher, adjusted for a minimum opening of $\frac{1}{8}$ inch. The ground clay was screened through a sieve equivalent to 12 mesh of the Tyler standard series. The material not passing the screen was run through a roll crusher, having smooth rolls, ten inches wide, and approximately 1/16 inch apart. This procedure was followed until the entire sample passed through the screen.

The ground sample was thoroughly blended and then quartered and subdivided so that the following representative samples could be obtained: 200 grams for microscopic examination, 2,000 grams for chemical analysis, 2,000 grams for screen analysis and Pyrometric Cone Equivalent determination.

Screen Analysis

A 150-gram sample was taken from the quantity set aside for screen analysis, placed on a set of standard Tyler testing sieves consisting of 14-, 20-, 28-, and 35-mesh and pan, and shaken in a Rotap for 15 minutes.

First and Third Sample

Screen	Residue 1st	Residue 3rd	Average Residue	Per Cent	Per Cent Cumulative
14	16.5	16.6	16.55	11.04	11.04
20	22.2	24.0	23.10	15.39	26.43
28	21.0	20.2	20.60	13.75	40.16
35	15.5	15.1	15.30	10.20	50.36
48	10.4	10.5	10.45	6.96	57.32

Second and Fourth Sample

Screen	Residue 2nd	Residue 4th	Average Residue	Per Cent	Per Cent Cumulative
65	10.4	9.8	10.10	6.73	64.05
100	9.5	9.8	9.65	6.43	70.48
150	5.4	5.8	5.60	3.73	74.21
200	5.9	5.6	5.75	3.83	78.04
Thru 200 ..	32.9	33.0	32.95	21.96	
	149.7	150.4	150.05	100.00	

[1] This chapter is reprinted from Engineering Experiment Station Bull. 81.

SUMMARY TABLE OF TESTS BY GEOLOGICAL SURVEY OF OHIO AND ENGINEERING EXPERIMENT STATION

Sample Number	Geologic Classification: System	Series or formation	Subdivision or member	Kind of material	Name of Firm (1929)	Location: Place	Section	Township	County
47	Devonian	Ohio	Chagrin	Shale	Cleveland Brick & Clay Co.	Cleveland	..	Newburg	Cuyahoga
48	Devonian	Ohio	Chagrin	Shale	Graham Clay Products Co.	Conneaut	..	Conneaut	Ashtabula
45	Mississippian	Bedford		Shale	Berea Brick & Tile Co.	Near Berea	..	Strongsville	Cuyahoga
46	Mississippian	Bedford		Shale	Cleveland Builders Supply & Brick Co., Pearl Plant	Cleveland	..	Brooklyn	Cuyahoga
42	Mississippian	Cuyahoga		Shale	Mansfield Shale Products Co.	Near Mansfield	25	Weller	Richland
43	Mississippian	Cuyahoga		Shale	Medal Brick & Tile Co.	Wooster	4	Wooster	Wayne
44	Mississippian	Cuyahoga				Orangeville	..	Pymatuning	Mercer Co., Pa.
21	Pennsylvanian	Pottsville	Anthony		State Brick Plant	Near Junction City	5	Jackson	Perry
23	Pennsylvanian	Pottsville	Anthony	Shale	Wadsworth Brick & Tile Co.	Wadsworth	..	Wadsworth	Medina
12	Pennsylvanian	Pottsville	Anthony and Massillon	Shale	American Vitrified Products Co., Plant No. 25	Barberton	..	Norton	Summit
22	Pennsylvanian	Pottsville	Anthony	Shale	Universal Sewer Pipe Co., Plant No. 2	Palmyra	..	Palmyra	Portage
13	Pennsylvanian	Pottsville	Massillon	Shale	Belden Brick Co.	Somerset	3	Reading	Perry
14	Pennsylvanian	Pottsville	Anthony, Massillon, & Bear Run	Shale	Camp Brothers Co.	Mogadore	..	Springfield	Summit
19	Pennsylvanian	Pottsville	Lower Mercer	Shale	Portsmouth Clay Products Co.	South Webster	15	Bloom	Scioto
18	Pennsylvanian	Pottsville	Lower Mercer	Shale	Dalton Clay Products Co.	East Greenville	7	Tuscarawas	Stark
20	Pennsylvanian	Pottsville	Upper Mercer	Shale		Union Furnace	26	Starr	Hocking
17	Pennsylvanian	Pottsville	Middle Mercer Upper Mercer	Shale	Junction City Sewer Pipe Co.	Junction City	10	Jackson	Perry
16	Pennsylvanian	Pottsville	Tionesta	Shale	Sugar Creek Clay Products Co.	Sugar Creek	1	Sugar Creek	Tuscarawas
15	Pennsylvanian	Pottsville	Homewood	Shale	Federal Clay Products Co.	East Sparta	27	Pike	Stark
34	Pennsylvanian	Allegheny	Clarion	Shale	McArthur Brick Co.	McArthur	28	Elk	Vinton
36	Pennsylvanian	Allegheny	Clarion	Shale	Nicholson Corporation	South Zanesville	11	Springfield	Muskingum
27	Pennsylvanian	Allegheny	Clarion	Shale	Belden Brick Co.	Port Washington	..	Clay	Tuscarawas
30	Pennsylvanian	Allegheny	Clarion	Shale	Fisher Brothers Clay Co.	Sugar Creek	3	Sugar Creek	Tuscarawas
26	Pennsylvanian	Allegheny	Clarion	Shale	Belden Brick Co.	Canton	15	Canton	Stark
31	Pennsylvanian	Allegheny	Lower Kittanning	Shale	General Clay Products Co.	Baltic	25	Clark	Holmes
29	Pennsylvanian	Allegheny	Strasburg	Shale	Wm. E. Dee Co.	Oak Hill	24	Jefferson	Jackson
28	Pennsylvanian	Allegheny	Strasburg	Shale	Coshocton Brick Co.	Coshocton	..	Tuscarawas	Coshocton
25	Pennsylvanian	Allegheny	Strasburg	Shale	Alliance Clay Products Co.	Alliance	31	Smith	Mahoning
32	Pennsylvanian	Allegheny	Lower Freeport	Shale	Greendale Brick Co.	Greendale	6	Green	Hocking
37	Pennsylvanian	Allegheny	Lower Freeport	Shale	Zanesville Clay Products Co., Plant No. 2	Zanesville	4	Wayne	Muskingum
35	Pennsylvanian	Allegheny	Lower Freeport	Shale	National Fireproofing Co.	Waynesburg	29	Sandy	Stark
33	Pennsylvanian	Allegheny	Lower Freeport	Shale	Mapleton Clay Products Co.	Mapleton Station	23	Osnaburg	Stark
24	Pennsylvanian	Allegheny	Lower Freeport	Shale	Alliance Clay Products Co.	Alliance	31	Smith	Mahoning
39	Pennsylvanian	Conemaugh	Buffalo	Shale	Nelsonville Brick Co.	Nelsonville	30	York	Athens
38	Pennsylvanian	Conemaugh	Buffalo	Shale	Hisylvania Coal Co.	Glouster	9	Trimble	Athens
40	Pennsylvanian	Conemaugh		Shale		Chesapeake	32	Union	Lawrence
41	Pennsylvanian	Conemaugh	Summerfield Connellsville	Shale	Standard Stone & Brick Co.	McClainville	12	Pultney	Belmont
49	Permian	Washington	Creston Red	Shale	Marietta Shale Brick Co.	Marietta	30	Marietta	Washington
4	Pleistocene			Glacial Drift	B. F. Clark Tile Plant	Versailles	18	Wayne	Darke
5	Pleistocene			Glacial Drift	Delaware Clay Co.	Delaware	..	Delaware	Delaware
9	Pleistocene			Glacial Drift	A. W. Rife	Good Hope	..	Wayne	Fayette
1	Recent			Alluvial Silt and Clay	Mitchell Brick Co.	Saylor Park Cincinnati	35	Delhi	Hamilton
8	Pleistocene			Glacial Drift	Napoleon Brick & Tile Works	Napoleon	14	Napoleon	Henry
7	Pleistocene			Glacial Drift	Monroeville Clay Products Co.	Monroeville	..	Ridgefield	Huron
11	Pleistocene			Glacial Drift	West Mansfield Clay Products Co.	West Mansfield	..	Bokes Creek	Logan
3	Pleistocene			Glacial Drift	Celina Brick Co.	Celina	36	Jefferson	Mercer
6	Pleistocene			Glacial Drift	Haviland Clay Works Co.	Haviland	25	Blue Creek	Paulding
2	Pleistocene		Minford	Alluvial Silt and Clay		Minford	3	Madison	Scioto
10	Pleistocene			Glacial Drift	Stryker Drain Tile Co.	Near Stryker	..	Springfield	Williams

Sample Number	Chemical Analysis: Water hygroscopic, H_2O-	Water combined, H_2O+	Silica, SiO_2	Alumina, Al_2O_3	Titanic oxide, TiO_2	Phosphorus pentoxide, P_2O_5	Ferric oxide, Fe_2O_3	Ferrous oxide, FeO	Lime, CaO	Magnesia, MgO	Sodium oxide, Na_2O	Potassium oxide, K_2O	Manganese oxide, MnO	Sulphur, S	Sulphur trioxide, SO_3	Ferrous sulphide, FeS_2	Carbon dioxide, CO_2	Carbon organic, C	Oxide Ratio: Sum of K_2O, Na_2O, FeO, CaO and MgO	Al_2O_3	Sum of SiO_2 and TiO_2
47	1.50	5.11	59.56	15.90	1.05	.18	5.72	4.06	.62	.26	.42	3.50	.04	.....	.....	.....	.88	.27	.923	1.00	3.832
48	1.41	5.50	59.40	18.14	.80	.22	3.08	3.14	1.90	1.72	.35	3.01	.04	.....	1.45	.24	.52	.27	.657	1.00	3.231
45	1.17	4.50	61.70	18.68	1.12	.08	3.36	1.68	.48	1.38	.30	2.99	.03	.....	.22	1.69	.12	.68	.573	1.00	3.367
46	1.96	5.45	57.30	13.06	1.30	.15	14.08	1.36	.63	1.62	.35	2.60	.04	.04	.....	.....	.16	.23	1.477	1.00	4.483
42	.83	5.72	59.84	19.45	.83	.21	2.43	2.51	.62	2.60	.27	2.89	.03	.....	.05	.22	.93	.41	.624	1.00	3.104
43	.90	5.93	62.75	12.91	1.22	.11	4.61	3.02	.50	1.21	.14	3.28	.06	.....	.16	.....	.60	.56	.896	1.00	4.678
44	2.62	5.62	60.22	19.60	.86	.18	4.49	1.24	.46	1.29	.20	2.60	.07	.10	.....	.....	.23	.60	.547	1.00	3.125
21	1.52	6.88	58.14	17.68	1.10	.15	6.23	2.70	.38	.89	.19	2.88	.05	.07	.....	.....	.40	1.09	.709	1.00	3.358
23	.82	.....	75.24	10.96	.90	.15	4.01	.....	.40	.61	.51	2.63	Trace	.....	.....	.....	.....	.....	.708	1.00	6.960
12	.90	6.01	61.47	16.80	1.01	.18	2.60	4.23	.44	.74	.22	2.21	.12	.....	Trace	.26	2.35	1.37	.623	1.00	3.739
22	1.10	6.78	58.60	21.88	1.25	.12	4.29	.74	.25	1.03	.13	2.41	.01	.....	.33	Trace	.30	.93	.384	1.00	2.740
13	.77	4.25	68.92	14.75	.97	.08	4.15	2.20	.24	.80	.04	2.40	.05	.01	.....	.....	.15	.45	.638	1.00	4.734
14	.78	5.27	60.62	18.14	1.06	.11	2.05	4.10	.32	1.72	.10	2.36	.06	.....	.26	.38	1.85	1.01	.590	1.00	3.406
19	.76	.....	56.64	18.33	1.30	.21	8.70	.....	.66	2.09	.78	2.92	Trace	.....	.....	.....	.....	.....	.833	1.00	3.177
18	.40	4.88	66.66	14.28	.83	.12	1.95	2.93	.58	1.68	.47	2.46	.05	.....	.12	.47	.85	1.19	.751	1.00	4.724
20	1.55	5.09	58.90	18.39	1.03	.15	7.34	1.35	.27	1.40	.41	2.27	.16	.04	.....	.....	.43	.55	.676	1.00	3.338
17	1.60	5.72	64.16	17.95	.99	.06	3.26	.33	.22	.97	.31	1.97	.04	.....	.06	.....	.10	.86	.478	1.00	3.623
16	1.07	5.65	58.25	21.77	1.01	.25	2.29	3.28	.42	1.08	.06	2.65	.06	.05	.....	.....	.65	.18	.466	1.00	2.737
15	1.68	5.05	61.25	16.21	1.10	.25	7.22	1.02	.70	1.66	.33	2.30	.07	.02	.....	.....	.33	.18	.818	1.00	3.838
34	1.19	5.54	57.50	18.01	.99	.08	5.02	4.12	.26	1.80	.24	3.04	.06	.....	.18	.....	1.10	.79	.786	1.00	3.252
36	.77	4.46	64.16	16.98	.92	.16	3.33	2.50	.75	1.60	.49	2.50	.07	.09	.....	.....	1.90	.33	.642	1.00	3.841
27	1.63	6.51	58.80	18.53	1.05	.28	4.40	2.61	.42	1.92	.19	2.41	.07	.06	.....	.....	.56	.22	.635	1.00	3.244
30	1.75	5.40	58.17	19.29	1.14	.12	6.56	1.33	.43	1.60	.14	3.30	.03	.....	Trace	.....	.15	.44	.671	1.00	3.099
26	1.16	5.50	60.04	18.80	1.10	.27	3.29	2.84	.68	1.53	.22	2.99	.05	.09	.....	.....	.75	.81	.590	1.00	3.271
31	.92	5.60	59.82	19.29	1.27	.16	4.92	1.74	.56	1.80	.39	2.90	.07	.....	.19	.....	.29	.22	.616	1.00	3.175
29	2.05	5.63	58.01	22.14	1.29	.17	3.58	.65	1.16	1.83	.20	2.82	.04	.....	.12	.....	.35	.19	.448	1.00	2.686
28	1.24	6.08	62.10	18.43	1.27	.14	5.15	.81	.60	.65	.30	2.69	.05	.04	.....	.....	None	.50	.528	1.00	3.446
25	1.50	6.50	50.90	18.81	.96	.33	.28	9.10	1.65	1.10	.11	2.20	.11	.02	.....	.....	6.60	Trace	.771	1.00	2.774
32	1.10	5.59	58.21	20.17	1.27	.18	5.29	1.42	1.12	1.78	.22	2.88	.08	.....	.18	.....	.51	.15	.607	1.00	2.958
37	.77	6.71	56.95	15.08	.96	.19	4.71	5.19	.80	2.35	.56	3.04	.08	.....	.03	.50	1.50	.83	1.098	1.00	3.852
35	1.44	5.83	57.92	17.91	1.15	.28	3.86	3.12	.68	1.96	.44	3.02	.07	.....	.17	.27	.70	1.35	.721	1.00	3.313
33	1.21	5.22	60.74	17.78	1.29	.24	5.43	1.59	.55	1.79	.41	2.97	.07	.10	.....	.....	.15	.62	.690	1.00	3.502
24	.50	5.10	62.81	16.71	1.01	.17	3.10	3.40	.71	1.88	.33	2.64	.04	.10	.....	.....	1.02	.77	.705	1.00	3.829
39	1.77	5.06	60.42	18.67	1.14	.11	5.77	1.33	.60	2.19	.35	2.47	.05	.....	.04	.....	.10	.12	.652	1.00	3.303
38	1.70	5.19	61.42	18.08	1.31	.11	6.65	.77	.50	1.72	.22	2.25	.06	.....	Trace	.....	.02	.14	.636	1.00	3.475
40	1.95	5.50	56.30	20.96	1.05	.20	3.65	2.07	1.82	2.05	.44	2.93	.06	.01	.....	.....	1.16	.02	.604	1.00	2.745
41	1.51	5.02	54.86	17.22	.95	.10	5.16	3.40	3.64	1.81	.30	2.07	.07	.....	.09	.....	3.77	.19	.925	1.00	3.246
49	1.73	.....	55.80	18.65	1.45	.19	8.16	.....	2.08	1.95	.93	3.33	Trace	.....	.....	.....	.....	.....	.838	1.00	3.079
4	1.95	4.25	64.44	15.56	1.02	.12	4.79	.84	1.43	1.78	.27	2.32	.07	.....	.08	.....	.22	.95	.708	1.00	4.214
5	1.86	3.40	60.91	12.38	.70	.15	5.29	1.35	3.70	2.68	.46	2.40	.06	.02	.....	.....	4.20	.55	1.244	1.00	4.988
9	2.15	4.30	68.07	11.55	.68	.15	4.71	1.17	1.20	1.51	.82	2.27	.11	Trace	.....	.....	.44	1.07	.980	1.00	5.965
1	1.55	3.77	71.56	12.21	.86	.14	3.88	1.35	.55	1.21	.68	1.82	.09	.02	.....	.....	.28	.25	.752	1.00	5.942
8	1.50	4.21	64.22	15.44	.70	.12	4.25	1.22	1.60	1.73	1.10	2.71	.05	.....	.07	.....	.35	.98	.792	1.00	4.212
7	1.65	4.04	67.18	11.70	.72	.09	5.39	.75	2.54	1.43	.53	2.22	.08	.....	Trace	.....	1.17	.55	1.059	1.00	5.811
11	2.32	4.70	61.61	14.46	.72	.22	5.29	1.16	2.55	1.36	.47	2.35	.18	.03	.....	.....	1.82	.80	.887	1.00	4.325
3	1.63	3.96	71.80	12.35	.88	.20	2.73	.90	.61	1.36	.46	2.31	.12	.01	.....	.....	.32	.60	.665	1.00	5.901
6	2.85	4.43	62.62	13.33	.77	.21	5.86	1.52	1.80	2.05	.72	2.90	.06	.01	.....	.....	.60	.55	1.089	1.00	4.771
2	2.52	5.27	55.91	17.30	1.00	.18	8.58	1.33	.90	2.41	.45	3.25	.06	.04	.....	.....	.72	.25	.931	1.00	3.300
10	1.24	3.44	58.63	11.22	.70	.16	4.65	1.32	6.50	2.95	.55	2.40	.07	Trace	.....	.....	5.90	.38	1.601	1.00	5.302

Sample Number	Properties in Plastic and Dry States: Slaking time, minutes	Water of plasticity, per cent	Shrinkage water, per cent	Pore water, per cent	Dry volume shrinkage, per cent	Calculated linear shrinkage, per cent	Measured dry linear shrinkage, per cent	Dry apparent porosity, per cent	Dry bulk specific gravity	Dry apparent specific gravity	Dry modulus of rupture, pounds per sq. in.	Extrusion length, inches	Dry specific impact strength, centimeter kilograms per sq. centimeter	Coefficient of plasticity
47	58.40	17.77	4.92	12.85	10.05	3.34	3.37	23.88	2.03	1.91	304	3.68	1.19	1.695
48	10.38	21.07	6.09	10.13	11.44	3.68	3.13	27.44	1.90	1.91	297	3.33	1.14	1.602
45	13.70	19.68	5.34	14.34	10.48	3.38	3.58	27.61	1.95	1.97	284	4.13	1.39	1.233
46	128.47	22.65	8.33	13.79	16.59	5.35	4.56	24.08	1.98	1.94	437	4.90	1.20	1.865
42	49.76	20.94	6.97	13.97	12.61	4.35	4.12	26.00	1.94	1.91	247	4.16	1.08	.897
43	18.22	19.90	4.78	14.12	9.29	3.01	2.85	26.83	1.94	1.93	221	3.16	1.22	1.302
44	18.37	24.61	7.65	16.96	14.26	4.54	4.97	29.69	1.86	1.89	244	2.42	1.18	1.008
21	15.57	19.58	5.71	13.85	16.58	3.41	2.65	30.63	1.86	1.93	305	2.47	1.29	.969
23	26.60	16.24	4.27	11.89	8.54	2.77	1.56	23.53	1.96	1.72	229	2.64	1.19	1.592
12	22.33	18.23	6.73	11.50	13.70	4.33	2.67	23.61	2.02	1.90	290	2.64	1.22	1.368
22	26.45	20.90	5.63	14.76	11.74	3.77	3.39	30.09	1.87	1.91	314	4.42	1.29	1.166
13	12.89	18.16	5.45	12.71	10.85	3.49	2.46	25.50	1.88	1.92	296	3.51	1.25	1.475
14	11.3	19.43	5.57	13.86	10.89	3.50	3.63	25.21	1.96	1.92	272	3.59	1.22	1.393
19	Over 24 hours	20.18	4.16	16.02	8.06	2.62	2.36	28.25	1.69	1.93	243	3.39	1.29	1.168
18	13.0	17.42	4.19	16.07	8.06	2.60	2.04	25.80	1.80	1.88	261	3.15	1.04	1.078
20	47.66	21.64	6.14	15.50	11.52	3.79	2.02	27.30	1.87	1.88	235	3.20	1.22	1.732
17	22.76	20.62	5.28	15.34	9.97	3.32	3.34	28.40	1.88	1.90	278	4.46	1.43	1.512
16	11.3	19.97	4.81	15.16	9.19	2.98	2.95	27.28	1.92	1.92	292	3.17	1.18	1.334
15	12.51	19.51	5.19	14.32	9.81	3.17	3.24	24.75	1.87	1.83	193	1.70	1.39	1.025
34	15.47	19.29	4.82	14.47	9.00	2.93	2.58	27.73	1.86	1.88	183	2.78	1.28	1.448
36	16.75	17.70	2.72	13.98	7.21	2.35	2.70	24.13	1.94	1.87	268	3.10	1.36	1.775
27	20.51	19.60	6.17	8.68	11.93	3.83	2.81	26.14	1.88	1.91	310	.....	.....	1.189
30	9.60	19.47	5.54	13.93	10.05	3.49	3.38	27.36	1.92	1.91	284	4.27	1.22	1.447
26	6.75	19.32	5.21	14.01	10.14	3.27	3.42	25.13	1.91	1.93	340	3.27	1.25	2.012
31	11.76	20.57	5.68	14.89	10.90	3.51	3.33	28.79	1.91	1.95	317	3.74	1.33	1.154
29	14.90	22.14	8.08	14.06	15.40	4.99	3.88	27.80	1.89	1.93	345	4.51	1.19	1.788
28	31.25	20.83	6.76	17.74	13.58	4.34	3.92	24.72	1.92	1.89	505	4.26	1.41	1.048
25	21.22	17.11	6.43	10.68	13.44	4.29	4.17	23.23	2.14	2.00	267	2.42	1.34	1.466
32	15.78	19.31	4.66	14.65	8.96	2.90	2.22	30.33	1.92	1.99	193	2.33	1.29	1.044
37	9.48	18.09	3.94	14.15	7.73	2.51	2.04	29.38	1.95	2.00	202	3.12	1.13	1.423
35	11.22	16.95	3.81	13.14	7.54	2.45	2.68	23.02	1.86	1.79	293	2.72	1.28	1.301
33	5.71	20.38	4.09	16.29	7.65	2.49	2.15	26.21	1.87	1.87	250	1.87	1.22	1.479
24	5.76	19.33	5.82	13.61	10.91	3.51	2.42	25.70	1.90	1.88	160	1.64	1.18	1.618
39	13.70	19.88	5.62	12.82	10.83	3.49	2.10	23.49	1.93	1.87	407	2.03	1.53	1.662
38	13.36	19.81	6.06	13.75	11.91	3.83	2.77	24.37	1.96	1.91	470	2.47	1.22	1.868
40	19.45	16.83	5.40	11.43	11.03	3.55	3.03	23.00	2.05	1.97	280	2.62	1.26	1.976
41	83.73	17.58	6.32	11.26	13.88	4.43	3.90	20.15	2.08	1.95	471	3.82	1.34	3.805
49	23.78	19.03	7.89	11.14	16.51	5.23	4.34	19.65	2.09	1.95	573	4.18	1.40	2.550
4	24 hours	28.63	14.35	14.28	27.61	8.46	6.17	25.00	1.90	1.87	932	12.9	1.31	2.513
5	79.33	21.67	8.90	12.77	17.47	5.52	5.41	22.95	1.96	1.90	475	7.65	1.38	2.334
9	Over 24 hours	25.92	13.76	12.16	27.61	8.46	7.17	22.05	2.00	1.91	412	10.52	1.39	2.678
1	58.51	22.07	7.20	14.87	13.30	4.25	3.44	20.50	1.85	1.87	341	3.44	1.47	1.608
8	Over 24 hours	26.89	13.20	13.79	25.39	7.83	7.12	23.74	1.93	1.88	886	10.18	1.32	2.945
7	Over 24 hours	21.92	8.70	13.22	16.87	5.33	5.60	25.12	1.94	1.74	655	6.80	1.31	3.658
11	72.1	25.83	11.82	14.01	22.87	7.10	4.84	25.65	1.92	1.91	674	12.41	1.19	1.954
3	Over 48 hours	23.73	7.11	16.62	13.02	4.16	3.94	27.70	1.82	1.83	307	3.39	1.00	1.538
6	48 hours	29.88	15.40	14.48	29.20	8.91	6.66	25.22	1.94	1.91	945	12.5	1.07	3.315
2	44.97	29.31	13.00	16.31	25.86	7.97	5.91	28.80	1.90	1.99	383	18.37	1.18	2.160
10	24 hours	23.88	9.31	14.51	16.20	5.13	4.71	27.78	1.89	1.86	762	9.56	1.39	1.653

Sample Number	Properties After Firing: Minimum apparent porosity, at cone	Per cent	Maximum volume shrinkage, at cone	Per cent	Linear shrinkage, maximum calculated, at cone	Per cent	Minimum absorption, at cone	Per cent	Temperature, overfiring, at cone	°F	Best firing range	Softening point, P.C.E.	°F	Analyst	Physical properties by	Date of sampling	Sample No.
47	1	5.01	1	18.09	1	5.7	1	1.55	1	2,057	Cone 010 to cone 02	11-12	2,345-2,390	Downs Schaaf	C. R. Austin	Aug. 14, 1929	47
48	5	5.17	1	21.47	1	6.7	5	2.35	7	2,210	Cone 06 to cone 5	8-9	2,237-2,282	Downs Schaaf	C. R. Austin	Aug. 16, 1929	48
45	5	2.66	5	25.43	5	7.8	3	1.13	5	2,093	Cone 06 to cone 5	13	2,462	Downs Schaaf	C. R. Austin	Aug. 21, 1929	45
46	04	2.81	04	21.37	04	6.7	04	1.19	02	2,002	Cone 010 to cone 04	14-15	2,534-2,570	Downs Schaaf	C. R. Austin	Aug. 14, 1929	46
42	5	1.50	3	26.66	3	8.2	5	.63	5	2,156	Cone 06 to cone 5	13	2,570	Downs Schaaf	C. R. Austin	Aug. 2, 1929	42
43	5	5.17	5	23.10	5	7.2	5	2.18	5	2,237	Cone 06 to cone 5	11-12	2,345-2,390	Downs Schaaf	C. R. Austin	Aug. 2, 1929	43
44	5	1.96	3	28.23	3	8.6	5	.87	5	2,156	Cone 06 to cone 5	13	2,570	Downs Schaaf	C. R. Austin	Aug. 16, 1929	44
21	5	3.22	5	26.65	5	11.0	5	.33	7	2,210	Cone 06 to cone 4	12-14	2,462-2,534	Downs Schaaf	C. R. Austin	Sept. 26, 1929	21
23	7	10.06	7	12.30	7	4.2	7	7.61	Not determined		Cone 06 to cone 7	13	2,462	U. S. Bureau of Mines	C. R. Austin	July 31, 1929	23
12	7	9.35	7	20.65	7	6.4	7	4.11	9	2,282	Cone 06 to cone 7	14-15	2,534-2,570	Downs Schaaf	C. R. Austin	Aug. 1, 1929	12
22	7	9.53	7	23.68	7	7.2	7	4.22	Not determined		Cone 06 to cone 7	17-18	2,669-2,705	Downs Schaaf	C. R. Austin	Aug. 12, 1929	22
13	7	10.68	7	18.53	7	5.9	7	4.72	9	2,282	Cone 06 to cone 7	14-15	2,534-2,570	Downs Schaaf	C. R. Austin	Aug. 20, 1929	13
14	5	7.62	5	23.00	5	7.5	5	2.39	7	2,210	Cone 06 to cone 5	14-15	2,534-2,570	Downs Schaaf	C. R. Austin	Aug. 13, 1929	14
19	5	2.98	5	28.00	5	8.6	5	1.67	5	2,156	Cone 06 to cone 4	12-13	2,390-2,462	U. S. Bureau of Mines	C. R. Austin	June 19, 1929	19
18	7	12.87	7	18.51	5	5.8	7	6.00	7	2,210	Cone 06 to cone 7	12-13	2,390-2,462	Downs Schaaf	C. R. Austin	Aug. 9, 1929	18
20	7	3.21	7	26.51	7	8.1	7	1.27	7	2,210	Cone 06 to cone 7	10-11	2,300-2,345	Downs Schaaf	C. R. Austin	July 16, 1929	20
17	5	14.87	5	18.18	5	5.7	5	6.74	Not determined		Cone 06 to cone 5	16	2,642	Downs Schaaf	C. R. Austin	July 19, 1929	17
16	7	2.12	5	27.46	5	8.4	7	.89	5	2,156	Cone 06 to cone 4	14-15	2,534-2,570	Downs Schaaf	C. R. Austin	Aug. 7, 1929	16
15	7	3.90	7	23.18	7	7.2	7	1.68	9	2,282	Cone 06 to cone 7	14-15	2,534-2,570	Downs Schaaf	C. R. Austin	Sept. 11, 1929	15
34	5	2.40	5	25.80	5	7.8	5	1.01	7	2,210	Cone 06 to cone 5	14-15	2,534-2,570	Downs Schaaf	C. R. Austin	June 17, 1929	34
36	7	11.12	7	24.08	7	10.3	7	4.95	7	2,210	Cone 06 to cone 5	12	2,390	Downs Schaaf	C. R. Austin	July 24, 1929	36
27	8	1.55	5	25.62	5	7.8	8	.67	7	2,210	Cone 06 to cone 5	13	2,462	Downs Schaaf	C. R. Austin	Sept. 12, 1929	27
30	5	1.98	3	26.81	3	8.2	5	.84	7	2,210	Cone 06 to cone 5	13	2,462	Downs Schaaf	C. R. Austin	Aug. 7, 1929	30
26	5	1.24	3	25.00	5	8.1	5	.53	5	2,156	Cone 06 to cone 3	10	2,300	Downs Schaaf	C. R. Austin	Sept. 6, 1929	26
31	7	5.10	5	25.63	5	7.9	7	2.20	7	2,210	Cone 06 to cone 5	13-14	2,462-2,534	Downs Schaaf	C. R. Austin	Aug. 6, 1929	31
29	7	2.24	7	25.20	7	7.8	7	.97	9	2,282	Cone 06 to cone 5	16	2,642	Downs Schaaf	C. R. Austin	June 20, 1929	29
28	8	6.20	8	22.63	7	7.0	8	2.67	9	2,282	Cone 06 to cone 5	16	2,642	Downs Schaaf	C. R. Austin	Aug. 6, 1929	28
25	7	6.23	5	20.84	3	6.5	7	2.74	7	2,210	Cone 08 to cone 5	11-12	2,345-2,390	Downs Schaaf	C. R. Austin	Sept. 7, 1929	25
32	7	3.54	3	24.31	3	7.5	7	1.53	7	2,210	Cone 06 to cone 5	14	2,534	Downs Schaaf	C. R. Austin	July 17, 1929	32
37	5	4.81	5	28.18	5	8.6	5	2.00	7	2,210	Cone 06 to cone 5	9-10	2,282-2,300	Downs Schaaf	C. R. Austin	July 24, 1929	37
35	7	5.39	5	27.33	5	8.4	7	2.21	7	2,210	Cone 06 to cone 5	11	2,345	Downs Schaaf	C. R. Austin	Sept. 12, 1929	35
33	7	2.04	5	25.81	5	7.9	7	.88	7	2,210	Cone 06 to cone 5	12	2,390	Downs Schaaf	C. R. Austin	Sept. 10, 1929	33
24	7	8.24	7	21.91	7	6.8	7	3.69	9	2,282	Cone 06 to cone 7	13	2,462	Downs Schaaf	C. R. Austin	Sept. 7, 1929	24
39	7	1.24	5	22.80	5	7.1	7	.53	7	2,210	Cone 06 to cone 5	12	2,390	Downs Schaaf	C. R. Austin	July 16, 1929	39
38	7	4.54	5	23.40	5	7.3	7	1.93	7	2,210	Cone 06 to cone 5	11-12	2,345-2,390	Downs Schaaf	C. R. Austin	July 18, 1929	38
40	5	5.08	1	19.05	1	6.0	5	2.17	5	2,156	Cone 06 to cone 4	11	2,345	Downs Schaaf	C. R. Austin	June 27, 1929	40
41	5	4.94	3	17.91	3	5.6	5	2.16	6	2,174	Cone 06 to cone 4	9	2,282	Downs Schaaf	C. R. Austin	July 23, 1929	41
49	3	3.47	3	20.60	3	6.4	5	.39	5	2,156	Cone 08 to cone 3	9	2,282	Downs Schaaf	C. R. Austin	June 29, 1929	49
4	01	5.47	01	20.68	01	6.5	01	2.44	01	2,030	Cone 012 to cone 04	2	2,075	Downs Schaaf	C. R. Austin	June 6, 1929	4
5	01	17.03	01	15.80	01	5.0	01	7.98	2	2,075	Cone 08 to cone 01	5	2,156	Downs Schaaf	C. R. Austin	June 7, 1929	5
9	06	26.26	06	3.58	06	1.2	06	13.72	05	1,886	Cone 010 to cone 05	4-5	2,129-2,156	Downs Schaaf	C. R. Austin	June 10, 1929	9
1	7	13.95	7	17.79	7	5.6	7	6.47	9	2,282	Cone 06 to cone 7	10-11	2,300-2,345	Downs Schaaf	C. R. Austin	June 11, 1929	1
8	04	8.73	06	20.33	06	6.3	01	3.05	02	2,003	Cone 012 to cone 04	3-4	2,093-2,129	Downs Schaaf	C. R. Austin	June 4, 1929	8
7	1	10.38	1	20.20	1	6.3	1	4.37	3	2,093	Cone 08 to cone 1	6	2,174	Downs Schaaf	C. R. Austin	June 30, 1929	7
11	01	7.25	01	23.04	01	7.2	01	3.16	2	2,075	Cone 010 to cone 01	6	2,174	Downs Schaaf	C. R. Austin	June 7, 1929	11
3	7	4.98	5	25.00	3	7.7	7	2.26	7	2,210	Cone 06 to cone 5	10	2,300	Downs Schaaf	C. R. Austin	June 5, 1929	3
6	06	16.16	06	13.18	06	4.2	06	8.09	04	2,174	Cone 012 to cone 06	5-6	2,156-2,174	Downs Schaaf	C. R. Austin	June 5, 1929	6
2	06	11.48	06	21.90	06	6.8	06	5.30	04	1,922	Cone 010 to cone 06	14-15	2,534-2,570	Downs Schaaf	C. R. Austin	Sept., 1929	2
10	3	1.69	3	25.94	3	8.0	3	.75	2	2,075	Cone 04 to come 1	3	2,093	Downs Schaaf	C. R. Austin	June 5, 1929	10

Following this procedure the residue on each screen was weighed. Another 150-gram sample obtained by quartering was analyzed on the 48-, 100-, 150-, and 200-mesh screens. Check analyses were made in each case.

This method of procedure was necessary as the full set of screens could not be run at one time. The process gave satisfactory results.

Pyrometric Cone Equipment

The Pyrometric Cone Equivalent[1] of all samples was determined in a horizontal muffle (Palo) furnace.

Cone plaques capable of holding three cones in a row were made of 50 per cent plastic fire clay and 50 per cent aluminous grog and prefired to 1500° F. In running the Pyrometric Cone Equivalent tests, the standard cones used were placed at each end and the test cone in the center of the plaque. Plastic fire clay of the same kind as used in the making of the cone plaques was used to fasten the cones in the plaque. The cones were cut to 1¼ inch lengths and imbedded ¼ inch in the plaque. The rate of heating was standard.

Forming of Test Pieces

The clay was formed in a machine having a central auger 19 inches long with 3-inch blades placed on a 2½-inch diameter shaft, and a side auger at the charging end 8 inches long with 2½-inch blades placed on a 2½-inch diameter shaft. The barrel of the machine was 8⅝ inches long and tapered from 8 inches to 6¼ inches in diameter. The expansion chamber was 3⅜ inches long going from 6 inches in diameter to an approximately rectangular shape 6 by 3¾ inches. The die fastened to this was 2⅞ inches long, with opening tapering from 2 inches square at the entrance end to 11⅛ inches square at exit end. The die was cast of phosphor bronze at the Station. Even with Lower Kittanning clay, which is rather prone to lamination, this die produced test bars that were very satisfactory.

The sample of clay to be prepared was placed in a wheelbarrow, mixed by hand with water, and then pugged through the auger machine (die removed) until well mixed, judging the proper consistency by the feel and the manner in which the clay flowed through the machine.

When a homogeneous material of proper consistency was obtained, the die was put on and a column of clay for cutting test bars was run out on an oiled table. From each sample fifty 2-inch bars were made; also a number of 6-inch bars, the maximum from one clay being 75; and additional samples as needed. The 2-inch bars were immediately stored in a moist vessel to prevent evaporation until weight and plastic volumes could be determined.

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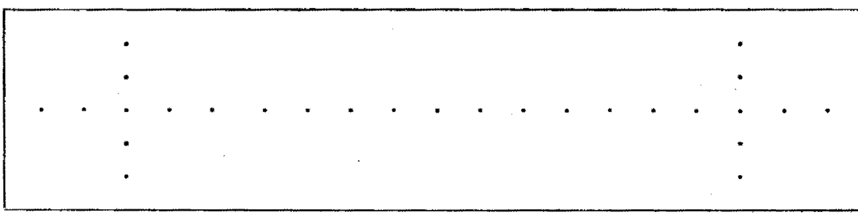
[1] Pyrometric Cone Equivalent is an index of the heat-resisting qualities or refractoriness of ceramic materials. Cones of the material to be tested, prepared in standard size and shape, are heated with standard pyrometric cones at a definite rate. The standard cone which fuses at the same time as the test cone determines the Pyrometric Cone Equivalent of the material under consideration.

Device for Placing Shrinkage Marks

The usual way to place shrinkage marks on a bar is to make a lengthwise mark with a rule and knife blade, and two crossmarks 5 inches apart. In these tests an automatic marker was used on the 6-inch bars. It was a wooden wheel $3\frac{11}{16}$ inches in diameter and $1\frac{1}{8}$ inches wide, in the periphery of which were driven small brads about 3/16 inches apart, protruding 1/16 inch, and sharpened to a fine point. A row of similar brads was placed perpendicular to those around the wheel in such a way that one revolution would mark off two 5-inch sections, each separated from its fellow by about an inch.

This wheel was supported over the extruding column in such a way that friction would cause it to rotate and leave the impression of the brads on the clay surface. The top of each 6-inch bar had this appearance:



Impact Bars

The impact bars were formed in an extrusion press of original design, made from a 2-inch pipe approximately 16 inches long capped at both ends, each cap filled with babbit metal to a depth of $\frac{3}{4}$ inch In one cap was an opening or die, $\frac{1}{2}$-inch square, with corners slightly rounded. The other cap was drilled and threaded to take a $\frac{3}{4}$-inch threaded rod pressing against a steel piston. When the pipe was filled with a properly mixed sample of the clay, the die-cap screwed on, and the rod turned by means of a crank, the clay was forced out of the die and onto a pallet where it was cut into $3\frac{1}{4}$-inch lengths. Thirty bars of each sample were made.

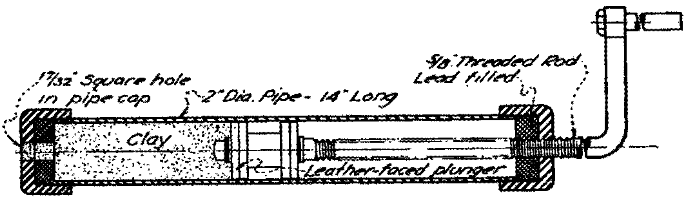
Drying of Test Pieces

The test pieces were left on steel pallets until they were air dry. They were then placed in a Hurricane drier. No attempt was made to control the humidity. In this type of drier, air is taken in through a 4-inch diameter opening at the bottom, blown by a fan over electric heating coils, and exhausted through a 4-inch opening at the top of the drier. For this test, the exhaust opening was kept half closed, thus causing a certain amount of recirculation of air. The samples were dried for 5 hours at a temperature of $150 \mp 5°$ F. The temperature was then raised to 250° F. and held at that figure for 19 hours.

DETERMINATION OF GREEN AND DRY PROPERTIES

Extrusion Strength

The extrusion strength determination is made by allowing a clay column to flow unsupported from a 1-inch die on an auger machine until



EXTRUSION PRESS

it breaks down under its own weight. The average length of ten pieces breaking from the column is taken as the extrusion strength. Concerning this test Ellis Lovejoy[1] says:

> Breaks under three inches in length rank a clay as impractical for stiff-mud products; over three inches a brick product is practical; over four inches small hollow tile in simple shapes can be made; over five inches larger tiles are possible. These are minimums and a good working clay should have higher wet strength. The majority of the best working clays have wet strengths ranging from six to eight inches. Higher wet strengths in themselves are not objectionable, quite the contrary, but such higher strengths are usually accompanied by other faults of which the high wet strength may be an indication. These other faults are water of plasticity above normal, often stickiness, excessive lamination, hard and strong dry ware, drying shrinkage above normal, and bad drying behavior The last mentioned fault is the serious one, and if there is no cracking in the drying, wet strengths above eight inches are not seriously objectionable.[2]

The quantity of each sample was not sufficient for the standard extrusion-strength test. However, since it was desired to have an approximation of this test rather than no test at all, the piston machine used for making impact bars was also used for this test. It is realized that the introduction of the human factor enhances the possibility of error, but the rate of turning the crank and consequent rate of issuance of the clay column was kept as constant as possible and the valves obtained by this method are believed to be satisfactory for comparison with each other.

Water of Plasticity

The specimens used in this test consisted of 15 of the 2-inch bars cut from the column at the same time as the 6-inch bars.

After the forming the specimens were weighed, subjected to the reg-

[1] Consulting engineer, Columbus, Ohio.
[2] Personal communication to C. R. Austin.

ular drying treatment, and weighed again. The per cent water of plasticity was obtained by the standard formula.

Dry Volume and Calculated Linear Shrinkage

The remaining 15 of the 2-inch bars cut along with the 6-inch bars were used for this test.

The plastic volume was determined immediately in an overflow volumeter The bars were then subjected to the regular drying treatment.

The dried specimens were cooled in a desiccator and then placed in kerosene for 18 hours. The dry volume was then determined, and dry volume shrinkage and calculated dry linear shrinkage were calculated, using the standard formulas.

Dry Apparent Porosity

The test pieces used for determining the dry volume shrinkage were weighed while saturated with kerosene and the apparent porosity calculated by means of the standard formula.

$$\text{Per Cent Dry Apparent Porosity} = \frac{\text{Saturated Weight} - \text{Dry Weight}}{\text{Dry Volume} \times \text{Sp. Gr. of Kerosene}}$$

Shrinkage Water

Using the data obtained in getting apparent porosity and dry volume shrinkage of the dry volume trials, the shrinkage water was calculated according to standard formula.

Pore Water

With the data obtained for shrinkage water and water of plasticity, the pore water was calculated using the standard formulae .

Measured Dry Linear Shrinkage

The original length of the shrinkage marks placed on the 6-inch bars was 5 inches, as described previously under "Forming." After drying, these marks were measured with a rule graduated to hundredths of an inch and the linear shrinkage obtained by the following formula:

$$\text{Per Cent Dry Linear Shrinkage} = \frac{\text{Wet Length} - \text{Dry Length} \times 100}{\text{Dry Length}}$$

Dry Apparent Specific Gravity

The dry apparent specific gravity was determined by the following formula:

$$\text{Dry Apparent Specific Gravity} = \frac{W_f}{V_f - \dfrac{(S_f - W_f)}{K}}$$

W_f = Weight of dry test piece
S_f = Weight of Kerosene saturated test piece
V_f = Volume of dry test piece
K = Specific gravity of kerosene

The data obtained in getting the apparent porosity and dry volume shrinkage were used in calculating the dry apparent specific gravity.

Dry Bulk Specific Gravity

Using the data obtained for dry apparent porosity, the dry bulk specific gravity was determined by means of the following formula:

$$\text{Dry Bulk Specific Gravity} = \frac{W_d}{V_d}$$

W_d = Dry Weight
V_d = Dry Volume

Dry Modulus of Rupture

The machine used for these tests is an improvised form of the machine described in the *Journal of the American Ceramic Society,* Volume 11, 1928, page 514, with two ratios, 6:1 and 16:1. For dry specimens the 6 ratio is used, the load applied to the bar being 6 times the weight of the shot. A 3-inch span was used in most cases, but for specimens requiring a high breaking load, a 5-inch span was used. From the data the modulus of rupture was calculated by the method given in the Tentative Test Methods of the American Ceramic Society.

Dry Specific Impact Strength

After drying, the specific impact strength was determined by using a pendulum instrument of the Charpy type. In this instrument a hammer swings on a pendulum striking the clay bar, breaking it and swinging past. In swinging past, it carries a pointer with it indicating on a fixed scale the maximum angle of swing attained after breaking the bar.

The energy absorbed in breaking the bar is ascertained from the angle of swing and the specific impact strength calculated by the following formula, the average results of breaking 10 specimens being used:

$$S = \frac{E}{A}$$

S = Specific impact strength
E = Energy absorbed in centimeter kilograms
A = Cross sectional area of specimen in sq. cm.

Drying Tests

To divide the clays on a basis of drying behavior into three general classes, namely, clays with which extreme care must be taken, clays which dry properly with ordinary care, and clays with which little or no care is necessary to dry properly, the following test was devised.

The amount of clay necessary to form specimens 4 inches square and 1 inch thick was mixed with the correct amount of water and kneaded by hand. The clay was then pressed into a wooden mold and smoothed with a spatula. Immediately after removal from the mold the specimens were placed in an electric drier thermostatically controlled to within 5° of the desired temperature. Trials were made up and placed in the drier using temperatures of 150°, 200°, 300°, and 400° F., successively. When a specimen cracked, no further samples of the clay were made to be dried at higher temperatures. The clays were divided into three classes by the temperatures at which they cracked. Clays which cracked at 150° or 200° F. were placed in the extreme-care-necessary class. Clays which cracked at 300° or 400° F. were placed in the ordinary-care-necessary class. Clays cracking at temperatures only above 400° F. were placed in the little-or-no-care-necessary class.

Dry Modulus of Elasticity

The same machine used for determining the transverse strength was used for determining the dry modulus of elasticity. By means of brackets fastened to the top of the machine, three Ames dials were placed in position over the clay bar, one dial over each end and one in the center. A load equal to approximately $\frac{1}{10}$ of the total load was applied to the bar and the readings on all dials taken. Then a load equal to about $\frac{6}{10}$ of that required for breaking was applied and dial readings again taken.

From this test the deformation was ascertained, and as the load was known the modulus of elasticity was calculated in the regular manner.

Slaking

To facilitate observance of the completion of slaking, especially of short shale specimens which slake rapidly and dirty the water, the standard $2\frac{1}{2}$-mesh screen was placed upon the shoulder inside of a desiccator filled with water so as to cover the clay cube. This arrangement leaves the water above the shoulder clearer than ordinary while the water below the shoulder becomes murky, which does not matter. In exceptional cases a light was placed behind the desiccator to further aid observation.

The specimens were of pure clay and made as described under "Forming"; otherwise the test was in accordance with the standard test.

FIRING BEHAVIOR

Firing Procedure

In order to learn the usefulness of the clays and the particular purpose to which each was best suited, it was necessary to know the changes in physical properties occurring over the entire firing range. The physical properties, which included volume shrinkage, calculated linear shrinkage, apparent porosity, bulk specific gravity, and apparent specific gravity, were determined at two cone intervals throughout the firing range.

The standard method of test for behavior in firing was not followed. Instead of using draw trials, a separate firing was made to each desired cone. The kiln was then allowed to cool slowly and the true colors of the sample obtained. This method has the additional benefit of requiring no auxiliary furnace in which to cool the trials. Five trials of each of the different materials were fired at alternate cones instead of the three trials suggested by the Standard Test Methods, but in all other respects, rate of heating, volume determination, etc., the standard method was followed.

In the kiln, rows of fire brick were laid on edge about 2½ inches apart, running lengthwise, and on these were placed a floor of fire brick laid flat. The trials were laid two high on this floor. Five trials of each of the forty-nine samples completely covered the superimposed floor. Cone plaques having a range of two cones above the desired temperature to two cones below the desired temperature were placed at each corner and at the center of the setting.

Five trials of each sample were fired at each temperature. The trials of each sample always occupied the same position in the kiln. In case a firing was deemed too high or too low for a particular sample, its place in the kiln setting was taken by five trials upon which no volume determinations had been made. The volume of ware in the kiln was thus the same on any firing.

The rate of heating was controlled by a Leeds & Northrup recording potentiometer, but the end of the firing was indicated when the tip of the desired cone touched the base regardless of the potentiometer reading.

At the end of the firing the damper on the flue leading to the fan was closed, and after the first two hours during which a 300° F. temperature drop took place, the kiln was cooled at the rate of 80° F. per hour.

Standard Tests

The standard procedure of the American Ceramic Society was adhered to in this investigation for determining the following fired properties:

Fired apparent porosity
Fired absorption
Fired bulk specific gravity
Fired apparent specific gravity
Fired volume shrinkage
Fired calculated linear shrinkage

Fired Transverse Strength

Clay bars were fired to approximately the maximum and minimum temperatures of the firing range and the modulus of rupture determined in the standard manner. The same machine used for determining the dry transverse strength was used for the fired transverse strength, but the 16:1 ratio was used instead of the 6:1 ratio.

Fired Specific Impact Strength

Impact bars were fired to about the maximum and minimum temperatures of the firing range. The specific impact strength was determined by using the same method and apparatus as for obtaining the dry specific impact strength.

It was found that different results were obtained using different lengths of bars made from the same material. For this reason when comparing specific impact strengths it is necessary to know that the specimens were of the same length or comparison is impossible. The longer the bar, the higher the specific impact strength will be.

There appears to be no connection between transverse strength and impact strength. That is, one increases with the other until a certain degree of vitrification is reached, when the impact strength may fall to a value below that obtained five or six cones lower, while the transverse strength may be much higher than that obtained five or six cones lower. Probably the impact strength test is more a measure of brittleness than impact resistance; and as long as further vitrification forms enough glass to toughen the body, the impact strength increases. However, when vitrification increases to where the quantity of glass formed tends to make the body brittle rather than toughen it, the impact strength fails.

Crushing Strength

To determine the fired crushing strength, specimens in the forms of cubes 2 inches on a side were formed from the plastic clay.

After drying, samples having about the same maximum firing temperature were grouped and fired to the average temperature for the group in the same kiln in which the firing behavior of the specimens was determined. As in the firing range determinations, the volume of the setting and relative positions of the samples were kept the same.

Capping: The crushing strength specimens after firing had relatively uneven surfaces. To provide smooth parallel bearing faces, a mixture of 50 per cent Silex sand and 50 per cent sulphur was melted and applied to two opposite surfaces of the clay cube. Use was made of the drill press for this work. A smooth steel plate was placed on the table of the press and some of the molten mixture of sulphur and sand poured on it. The top surface of the clay cube was pressed firmly against the chuck of the press, which was lowered until the bottom face of the cube imbedded itself in the capping mixture.

A spatula was run around the clay cube in the sulphur-sand mixture so as to form a depression. The spindle was raised and the cube with its adhering sulphur and sand mixture removed. The excess sulphur and sand was readily knocked off, breaking at the depression, and not chipping off at the edges, as sometimes happens if no depression is made. The capped surface was then placed against the spindle and the operation repeated to cap the other end.

Breaking: A 100,000-pound Olsen testing machine was used for breaking the specimens. The top head was a flat plate, and the bottom head was on a ball and socket joint. A small load was applied and the specimen worked back and forth by hand, moving the ball and socket joint so that any imperfections in the two surfaces would not interfere with the test. It was found that unless the specimen was worked back and forth the ball and socket did not compensate for inequalities of the surface.

$$C = \frac{P}{a}$$

C = Crushing strength in pounds per square inch.
P = Total load in pounds
a = Cross sectional area in square inches of smallest section of test specimen

Salt Glazing

The trials ($1\frac{1}{8}'' \times 1\frac{1}{8}'' \times 2''$) that had been used for the water of plasticity determinations were used for the salt-glazing tests. Three specimens of each particular clay were used for each test.

To devise a standard method of procedure a shale from a plant producing salt-glazed ware was used. Trials $1\frac{1}{8}'' \times 1\frac{1}{8}'' \times 2''$ were made up from this clay, dried, and placed in the kiln to be used for the salt-glazing tests. The standard rate of heating for firing range trials was followed until 2100°F. was reached. The temperature was held constant at this point for two hours. Then the first salting was given. The damper was then lowered so that the salt fumes barely moved through the kiln. After about three minutes the damper was raised and when the temperature of the kiln came back to 2100°F. the temperature was held for fifteen minutes, then another salting given the ware. After each salting a draw trial was pulled from the kiln. After the eighth salting a good glaze of sufficient thickness was produced and the kiln closed off after 15 minutes of soaking at 2,100°F. This procedure was taken as standard in the firings that followed. Two were made, one using 2,100°F. as the salting temperature, and the other using 2,050°F. In each of these firings were trials of all specimens that would withstand the temperature used in the salt glazing. Another salt-glazing test was made at 2,100°F., using samples to which barium carbonate, $BaCO_3$, had been added to eliminate scum. This gave the color and effect of the glaze uninfluenced by the soluble salts in the clay.

Scumming Tests

At temperatures below cone 1, scum was quite noticeable on practically all of the samples. It was deemed advisable, therefore, to find the amount of barium carbonate necessary to add to each clay to overcome this difficulty.

The amount of clay used was sufficient to make up eight trials 1 x 4 x 4½ inches. Barium carbonate was added to four equal portions of this clay, each portion forming two trials, in the following proportions:

$$BaCO_3 : Clay :: 1:2000 :: 2:2000 :: 3:2000 :: 4:2000$$

The amount of barium carbonate to be used was mixed with the water required to make the clay workable and mixed thoroughly into the clay by hand. Two samples (4 x 4 x ½ inches) were made up for each concentration of barium carbonate used. The clay was then forced into a wooden mold inside a small tin pallet, the excess scraped off and the surface smoothed with a spatula. The trial was then removed from the mold and allowed to air dry 48 hours before placing in the electric drier. It was noticed that previous samples fired to cone 02 had the most scum on them in nearly all cases. Therefore all the trials to which barium carbonate had been added were fired to cone 02. After firing, the trials were inspected and the least amount of barium carbonate that eliminated the scum noted.

SCREEN ANALYSIS OF SAMPLES

	NAME OF FIRM (1929)	Screen Size	RETAINED ON 14	20	28	35	48	65	100	150	200	Pass 300
47	Cleveland Brick & Clay Co.	Per cent	4.08	12.88	16.59	13.36	8.47	7.47	6.79	3.78	3.58	23.00
		Cumulative	4.08	16.96	33.55	46.91	55.38	62.85	69.64	73.42	77.00	100.00
43	Graham Clay Products Co.	Per cent	4.97	11.74	16.38	13.91	9.61	8.30	7.27	3.87	4.04	19.91
		Cumulative	4.97	16.71	33.09	47.00	56.61	64.91	72.18	76.05	80.09	100.00
45	Berea Brick & Tile Co.	Per cent	9.30	16.14	14.68	11.59	8.50	8.10	7.31	3.99	3.32	17.07
		Cumulative	9.30	25.44	40.12	51.71	60.21	68.31	75.62	79.61	82.93	100.00
46	Cleveland Builders Supply & Brick Co.	Per cent	3.43	10.93	16.03	14.20	10.23	9.33	8.36	4.33	3.93	19.23
	Pearl Plant	Cumulative	3.43	14.36	30.39	44.59	54.82	64.15	72.51	76.84	80.77	100.00
42	Mansfield Shale Products Co.	Per cent	11.49	14.08	14.14	12.29	8.48	7.98	7.82	3.81	3.15	16.76
		Cumulative	11.49	25.57	39.71	52.00	60.48	68.46	76.28	80.19	83.34	100.00
43	Medal Brick & Tile Co.	Per cent	10.32	13.47	14.83	10.71	7.13	6.53	6.27	4.34	4.88	21.52
		Cumulative	10.32	23.79	38.62	49.33	56.46	62.99	69.26	73.60	78.48	100.00
44	Sample near Orangeville	Per cent	2.70	10.32	16.41	15.12	10.49	9.53	8.10	4.13	4.20	19.00
		Cumulative	2.70	13.02	29.43	44.55	55.04	64.57	72.67	76.80	81.00	100.00
21	State Brick Plant	Per cent	12.79	16.19	14.09	11.23	7.26	7.06	6.76	3.43	2.50	18.69
		Cumulative	12.79	28.98	43.07	54.30	61.56	68.62	75.38	78.81	81.31	100.00
23	Wadsworth Brick & Tile Co.	Per cent	8.97	14.86	13.45	8.61	5.26	5.23	4.96	3.04	4.67	31.95
		Cumulative	8.97	23.83	36.28	44.89	50.15	55.38	60.34	63.38	68.05	100.00
12	American Vitrified Products Co.	Per cent	13.16	11.84	10.50	8.30	6.50	6.96	6.92	4.72	5.58	25.52
	Plant No. 25	Cumulative	13.16	25.00	35.50	43.80	50.30	57.26	64.18	68.90	74.48	100.00
22	Universal Sewer Pipe Co.	Per cent	2.44	8.57	15.33	15.36	10.51	8.80	7.90	3.72	4.18	23.19
	Plant No. 3	Cumulative	2.44	11.01	26.34	41.70	52.21	61.01	68.91	72.63	76.81	100.00
13	Belden Brick Co. (Somerset)	Per cent	20.09	16.29	13.69	9.05	6.14	6.71	5.91	3.96	3.94	15.22
		Cumulative	20.09	36.38	49.07	58.12	64.26	70.97	76.88	80.84	84.78	100.00
14	Camp Brothers Co.	Per cent	1.67	7.08	13.82	13.39	9.63	9.56	10.51	6.58	6.27	22.49
		Cumulative	1.67	8.75	21.57	34.96	44.59	54.15	64.66	71.24	77.51	100.00

SCREEN ANALYSIS OF SAMPLES—Continued

	NAME OF FIRM (1929)	Screen Size	RETAINED ON 14	20	28	35	48	65	100	150	200	Pass 200
19	Portsmouth Clay Products Co.	Per cent	16.60	14.10	11.88	9.71	6.99	6.83	5.88	3.43	4.00	20.58
		Cumulative	16.60	30.70	42.58	52.29	59.28	66.11	71.99	75.42	79.42	100.00
18	Dalton Clay Products Co.	Per cent	1.90	5.87	10.07	11.00	8.47	8.90	10.44	6.20	5.97	31.18
		Cumulative	1.90	7.77	17.84	28.84	37.31	46.21	56.65	62.85	68.82	100.00
20	Shale near Union Furnace	Per cent	12.41	13.96	12.54	10.66	7.29	7.36	6.78	3.76	3.82	21.42
		Cumulative	12.41	26.37	38.91	49.57	56.86	64.22	71.00	74.76	78.58	100.00
17	Junction City Sewer Pipe Co.	Per cent	16.66	14.17	10.89	9.32	6.87	7.12	7.53	4.81	5.77	16.86
		Cumulative	16.66	30.83	41.72	51.04	57.91	65.03	72.56	77.37	83.14	100.00
16	Sugar Creek Clay Products Co.	Per cent	2.83	9.71	15.90	14.34	9.62	8.38	7.95	4.32	3.83	23.12
		Cumulative	2.83	12.54	28.44	42.78	52.40	60.78	68.73	73.05	76.88	100.00
15	Federal Clay Products Co.	Per cent	18.49	16.76	12.44	9.13	6.06	6.10	5.53	3.30	3.20	18.99
		Cumulative	18.49	35.25	47.69	56.82	62.88	68.98	74.51	77.81	81.01	100.00
34	McArthur Brick Co.	Per cent	5.79	18.07	15.59	11.72	7.75	6.85	5.30	5.93	2.15	20.85
		Cumulative	5.79	23.86	39.45	51.17	58.92	65.77	71.07	77.00	79.15	100.00
36	Nicholson Corporation	Per cent	4.46	10.08	13.70	10.97	7.40	8.03	8.85	6.04	6.37	24.10
		Cumulative	4.46	14.54	28.24	39.21	46.61	54.64	63.49	69.53	75.90	100.00
27	Belden Brick Co. (Port Washington)	Per cent	11.04	16.91	14.91	11.37	7.04	6.41	5.80	3.34	3.17	20.01
		Cumulative	11.04	27.95	42.86	54.23	61.27	67.68	73.48	76.82	79.99	100.00
30	Finzer Brothers Clay Co.	Per cent	3.57	9.34	16.10	14.57	9.78	8.45	7.42	4.06	4.22	22.49
		Cumulative	3.57	12.91	29.01	43.58	53.36	61.81	69.23	73.29	77.51	100.00
26	Belden Brick Co. (Canton)	Per cent	8.89	12.73	11.37	9.68	6.33	6.10	6.00	3.52	4.64	30.74
		Cumulative	8.89	21.62	32.99	42.67	49.00	55.10	61.10	64.62	69.26	100.00
31	General Clay Products Co.	Per cent	11.04	15.39	13.73	10.20	6.96	6.73	6.43	3.73	3.83	21.96
		Cumulative	11.04	26.43	40.16	50.36	57.32	64.05	70.48	74.21	78.04	100.00
29	Wm. E. Dee Co.	Per cent	3.40	12.58	15.18	13.15	9.27	8.05	6.84	7.17	3.17	21.19
		Cumulative	3.40	15.98	31.16	44.31	53.58	61.63	68.47	75.64	78.81	100.00

28	Coshocton Brick Co.	Per cent	11.39	15.65	13.69	10.32	7.06	6.96	6.76	4.00	3.76	20.41
		Cumulative	11.39	27.04	40.73	51.05	58.11	65.07	71.83	75.83	79.59	100.00
25	Alliance Clay Products Co. (Strasburg Shale)	Per cent	3.57	12.25	15.05	14.78	10.44	9.41	8.14	3.84	8.27	19.25
		Cumulative	3.57	15.82	30.87	45.65	56.09	65.50	73.64	77.48	80.75	100.00
32	Greendale Brick Co.*		.....	.....	.....	.....	.....	.....	.....	.....	.....	......
			.....	.....	.....	.....	.....	.....	.....	.....	.....	......
37	Zanesville Clay Products Co. Plant No. 2	Per cent	20.01	14.58	10.84	8.30	5.82	5.85	5.42	3.18	3.28	22.72
		Cumulative	20.01	34.59	45.43	53.73	59.55	65.40	70.82	74.00	77.28	100.00
35	National Fire Proofing Co.	Per cent	2.71	8.86	14.27	13.64	9.52	8.39	7.89	4.28	4.51	25.93
		Cumulative	2.71	11.57	25.84	39.48	49.00	57.39	65.28	69.56	74.07	100.00
33	Mapleton Clay Products Co.	Per cent	7.40	10.96	11.59	9.78	7.00	6.17	6.76	4.99	5.06	30.27
		Cumulative	7.40	18.36	29.95	39.73	46.73	52.90	59.66	64.65	69.71	100.00
24	Alliance Clay Products Co. (Lower Freeport Shale)	Per cent	2.26	7.73	13.41	12.77	8.99	8.49	8.86	6.24	5.84	25.41
		Cumulative	2.26	9.99	23.40	36.17	45.16	53.65	62.51	68.75	74.59	100.00
39	Nelsonville Brick Co.	Per cent	13.61	13.42	10.63	8.84	6.33	6.36	6.23	4.01	4.34	26.23
		Cumulative	13.61	27.03	37.66	46.50	52.83	59.19	65.42	69.43	73.77	100.00
38	Hisylvania Coal Co.	Per cent	13.17	13.04	10.55	8.83	6.25	6.42	6.61	5.06	5.29	24.79
		Cumulative	13.17	26.21	36.76	45.59	51.84	58.26	64.86	69.82	75.21	100.00
40	Shale near Chesapeake	Per cent	7.05	13.31	15.08	11.74	8.76	7.33	6.95	3.98	4.19	21.61
		Cumulative	7.05	20.36	35.44	47.18	55.94	63.27	70.22	74.20	78.39	100.00
41	Standard Stone & Brick Co.	Per cent	16.25	17.98	13.14	9.50	6.85	6.89	6.69	3.67	3.34	15.69
		Cumulative	16.25	34.23	47.37	56.87	63.72	70.61	77.30	80.97	84.31	100.00
49	Marietta Shale Brick Co.	Per cent	6.27	12.22	14.32	12.26	8.44	8.00	7.44	3.95	4.05	23.05
		Cumulative	6.27	18.49	32.81	45.07	53.51	61.51	68.95	72.90	76.95	100.00
4	B. F. Clark Tile Plant	Per cent	11.56	14.73	14.60	11.90	8.33	8.16	7.26	4.10	3.20	16.16
		Cumulative	11.56	26.29	40.89	52.79	61.12	69.28	76.54	80.64	83.84	100.00
5	Delaware Clay Co.	Per cent	3.04	9.75	14.09	14.16	9.88	9.52	9.08	4.84	4.04	21.60
		Cumulative	3.04	12.79	26.88	41.04	50.92	60.44	69.52	74.36	78.40	100.00
9	A. W. Rife	Per cent	2.69	9.05	15.09	13.74	9.79	9.52	8.68	4.66	4.26	22.52
		Cumulative	2.69	11.74	26.83	40.57	50.36	59.88	68.56	73.22	77.48	100.00
1	Mitchell Brick Co.	Per cent	3.88	7.14	9.52	8.64	6.10	7.34	10.28	6.53	6.50	34.07
		Cumulative	3.88	11.02	20.54	29.18	35.28	42.62	52.90	59.43	65.93	100.00
8	Napoleon Brick & Tile Co.	Per cent	4.02	9.73	14.00	13.60	10.68	10.87	10.22	5.06	4.09	17.73
		Cumulative	4.02	13.75	27.75	41.35	52.03	62.90	73.12	78.18	82.27	100.00

* No screen data on this sample

SCREEN ANALYSIS OF SAMPLES—Concluded

	NAME OF FIRM (1929)	RETAINED ON										
		Screen Size	14	20	28	35	48	65	100	150	200	Pass 200
7	Monroeville Clay Products Co....................	Per cent	3.46	9.13	13.96	11.80	8.22	7.74	8.70	4.82	5.88	26.29
		Cumulative	3.46	12.59	26.55	38.35	46.57	54.31	63.01	67.83	73.71	100.00
11	West Mansfield Clay Products Co................	Per cent	2.49	7.75	14.17	15.15	10.84	9.69	9.60	4.94	4.54	20.83
		Cumulative	2.49	10.24	24.41	39.56	50.40	60.09	69.69	74.63	79.17	100.00
6	Haviland Clay Works Co.........................	Per cent	1.91	8.62	15.07	16.07	11.19	10.29	9.92	5.08	4.61	17.24
		Cumulative	1.91	10.53	25.60	41.67	52.86	63.15	73.07	78.15	82.76	100.00
2	Sample near Minford............................	Per cent	8.16	14.39	15.19	14.12	9.06	8.13	7.16	3.40	2.63	17.76
		Cumulative	8.16	22.55	37.74	51.86	60.92	69.05	76.21	79.61	82.24	100.00
10	Stryker Drain Tile Co...........................	Per cent	2.05	7.74	14.28	15.22	9.74	8.50	7.46	3.42	3.23	28.36
		Cumulative	2.05	9.79	24.07	39.29	49.03	57.53	64.99	68.41	71.64	100.00
8	Celina Brick Co.................................	Per cent	8.89	11.25	12.22	11.75	9.32	8.48	8.39	4.16	4.96	20.58
		Cumulative	8.89	20.14	32.36	44.11	53.43	61.91	70.30	74.46	79.42	100.00

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(Prepared by Ethel S. Dean)

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